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TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

Volume 18

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HUBERT C. SKINNER
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TULANE UNIVERSITY OF LOUISIANA
New Orleans

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY is devoted primarily to the geology and paleontology of the coasts and adjacent land areas of the Gulf of Mexico and the Caribbean Sea. Each number contains an individual monographic study, or several minor studies. As volumes are completed, title pages and tables of contents will be distributed to subscribers and institutions exchanging the entire series.

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I. ABSTRACT

A study of *Quinqueloculina tuberculata* Cushman and Todd from the Moodys Branch Formation (Jackson, Eocene) at Jackson, Mississippi, eventually evolved into this report on the wall structure of the foraminiferal superfamily Miliolacea and its genera and species from the Gulf Coastal Plain.

From the Moodys Branch Formation *Massilina jacksonensis* Cushman and its variety *punctatocostata* Cushman have been assigned to the new genus *Tappanella; Quinqueloculina tuberculata* Cushman and Todd is considered to be the quinqueloculine stage of *Massilina jacksonensis* Cushman; *Miliola saxorum* Lamarck and *Miliola jacksonensis* Cushman remain as originally described.

From the Weches Formation (Claiborne, Eocene) at Smithville, Texas, *Spiroloculina smithvillensis* Feray (nomen nudum) is redescribed as *Texina ferayi,* n. sp., which in turn is selected as the type species for the new genus *Texina.*

The Cane River Formation (Claiborne, Eocene), a Louisiana lithologic unit equivalent to the Weches of Texas, contains *Spiroloculina lamposa* Hussey, which has been assigned to the genus *Neaguites,* new genus.

Species related to *Miliola* present in the Byram Formation (Oligocene) include: *Triloculina mississippiensis* Cushman, which has been selected as the type of a new genus *Picouina; Spiroloculina byramensis* Cushman and *Spiroloculina imprimata* Cushman, which have been assigned to the new genus *Neaguites;* and *Quinqueloculina byramensis* Cushman, which has been assigned to the genus *Miliola.*

Tappanella, Picouina, Neaguites and *Texina,* the foraminiferal genera described as new, are calcareous perforate; have pitted chamber walls; and most aper-

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tures have a trematophore (are cribrate). They are assigned to the family Miliolidae, because the type genus *Miliola* has the same structural features. These features in turn, necessitate an emended diagnosis of the superfamily Miliolacea to accommodate genera with calcareous perforate chamber walls.

II. INTRODUCTION

An enigmatic, knobby species of foraminifera, *Quinqueloculina tuberculata* Cushman and Todd (fig. 1), from the Moodys Branch Formation is responsible for this paper. While attempting to collect topotypes of this species, it became apparent that tubercles or knobs were neither restricted nor unique to *Q. tuberculata* (figs. 5 and 6); that knobs occurred only on weathered or fragmented specimens (fig. 2); and that the knobs were associated only with species with pits in the wall of the chambers. These observations led to an expansion of the study to include: 1) the wall structure of the superfamily Miliolacea; and 2) the pitted species described from Eocene and Oligocene formations in the Gulf Coastal Plain. This *Miliola* lineage includes species reported from the Weches and Cane River Formations (Claiborne, Eocene) in Texas and Louisiana, the Moodys Branch Formation (Jackson, Eocene) and the Red Bluff and Byram Formations (Oligocene) in Mississippi.

The holotype of *Q. tuberculata* was recovered from the type locality of the Moodys Branch Formation located, according to Cushman and Todd (1945, p. 81), on the "E. bank of Moody's Branch 250 feet upstream from bridge across Moody's Branch on Monroe Street, NE part of Jackson, Miss." Because the type locality of the Moodys Branch Formation is no longer accessible, the samples used herein, for the recovery of "topotypes" of *Q. tuberculata,* came from the alternate type locality located in Riverside Park at Jackson, Mississippi. These samples provided the same fauna, depositional environment and subsequent weathering conditions that affected the specimens of *Q. tuberculata* described by Cushman and Todd in 1945.

The Moodys Branch Formation of the Jackson Group, as described by Cushman and Todd (1945, p. 79), underlies the Yazoo Formation; however, it does not overlie the Cockfield and Yegua conformably. In Louisiana, at least, a major unconformity separates the Moodys Branch Formation from the underlying Cockfield Formation of the Claiborne Group. Anderson (1971, p. 96) states that the "Moodys Branch represents an open marine transgressive facies disconformably onlapping the deltaic Yegua and Cockfield Formations and the Gosport Formation, which is the beach facies of the Yegua-Cockfield."

The Weches sample were collected from the Viesca Member located on the right bank of the Colorado River at Smithville, Texas. Feray (1941, p. 14) reports that, "the [Weches] formation rests disconformably upon the Queen City sands in the outcrop section throughout most of Texas," and that the overlying Sparta contact is "more transitional in character" in Bastrop County, where the Smithville outcrop is located.

The Cane River Formation sample studied came from outcrops in a tributary to Limekiln Bayou located in section 3 of T. 8 N., R. 8 W., about six miles west of Natchitoches, Louisiana. The formation in this area conformably overlies the Carrizo Formation and underlies the Sparta Sand of the Claiborne, Eocene.

The Oligocene Series is represented by the Red Bluff Formation at the base of the series, and by the Byram Formation at the top below the Catahoula sands of the Miocene Series. Both formations apparently are conformable in their relationship with the underlying and overlying formations.

All specimens figured are deposited in the Louisiana State University Geoscience Museum (LSU GM).

III. SYSTEMATICS*

Order FORAMINIFERIDA Eichwald, 1830

Suborder MILIOLINA Delarge and Héruard, 1896

Emended Diagnosis (Loeblich and Tappan, 1964, p. 436): Test calcareous, *wholly or in part* porcelaneous, commonly with pseudochitinous lining, may also include some adventitious material in wall. Carboniferous-Recent.

Remarks: Only the chamber floor of the genus *Miliola* is porcelaneous and imperforate. The chamber wall attached to the chamber floor is calcareous perforate. (See Family Miliolidae for discussion of chamber wall.)

Superfamily MILIOLACEA Ehrenberg, 1839

Emended Diagnosis (Loeblich and Tappan, 1964, p. 436): Wall *calcareous perforate, pitted,* may have adventitious material in *chamber wall;* proloculus followed by *two chambers to whorl,* arranged in different planes; aperture single *and simple* or cribrate. Eocene-Oligocene.

Remarks: Fragments of the final chamber of the following species were mounted on cover glass slides with canada balsam to determine the microstructure of the chamber wall.

Miliola saxorum Lamarck (from Mississippi and France)
Miliola jacksonensis Cushman
Massilina jacksonensis Cushman (1935 version)
Massilina jacksonensis punctatocostata Cushman

All wall fragments of the above were translucent, revealing a myriad of intertwining dark brown to black thread-like structures randomly distributed throughout the chamber wall (fig. 8). None showed an interference figure with the converging lens in place and the Bertrand lens introduced in the polarizing microscope tube. This indicates, but does not prove conclusively, that the chamber walls of the above species and variety assigned herein to the superfamily Miliolacea are composed of granular calcite. To test the accuracy of these observations, fragments of the pitted Holocene porcelaneous chamber wall of *Triloculina bicarinata* d'Orbigny, mounted on a slide in canada balsam, also showed no interference figure; however, the fragments were opaque.

The proposed placement for the porcelaneous Miliolacea, as described previously is in a new superfamily, the Soritacea. The Soritidae and Alveolinidae, described in 1839, are the oldest families with porcelaneous genera. According to Loeblich and Tappan (1964, p. 506) however, the type genus of Alveolinidae "is unquestionably a junior objective synonym." It appears, therefore, that the genus *Sorites* is the logical choice of a type genus for the superfamily of all porcelaneous genera.

Family MILIOLIDAE Ehrenberg, 1839

Emended Diagnosis (Loeblich and Tappan, 1964, p. 458): Test free, septate; *chambers with floor, simple interior, and pitted surface;* typically with 2 chambers to whorl arranged in varying planes about longitudinal axis; aperture terminal, simple or cribrate. Eocene-Oligocene.

Remarks: The wall structure of the Miliolidae as described herein, is based upon a study of the type species of the family, *Miliola saxorum* Lamarck, from the Lutetien samples collected in the Paris Basin, France, and specimens from the Moodys Branch Formation in Jackson, Mississippi. The difference between the species from the two localities is considered to be insignificant, particularly with respect to the wall structure. The descriptions of the *M. saxorum* wall, however, are based principally upon the Moodys Branch Formation specimens for comparison with species related to the *M. saxorum* present in the Moodys Branch, but not in the Lutetien of France.

The chamber wall of the family

*Emendations to Loeblich and Tappan's 1964 definitions are in italics; vital omissions are discussed under Remarks.

Miliolidae in general terms: is calcareous perforate; can be extremely porous but not alveolar; and has a pitted exterior. The arcuate chamber wall is attached to a thick, flat chamber floor (fig. 16), which is porcelaneous and imperforate. The genera and species with these wall structures are:

Miliola saxorum Lamarck

Miliola jacksonensis Cushman

Miliola byramensis (Cushman) = *Quinqueloculina byramensis*

Miliola rolandi Andersen, new species

Tappanella punctatocostata (Cushman) = *Massilina jacksonensis punctatocostata*

Tappanella jacksonensis (Cushman) = *Massilina jacksonensis*

Picouina mississippiensis (Cushman) = *Triloculina mississippiensis*

Neaguites inusitatus Andersen, new species

Neaguites byramensis (Cushman) = *Spiroloculina byramensis*

Neaguites lamposus (Hussey) = *Spiroloculina lamposa*

Neaguites imprimatus (Cushman) = *Spiroloculina imprimata*

Texina ferayi, new species = *Spiroloculina smithvillensis* (nomen nudum)

Detailed characteristics of the Miliolidae are revealed in the scanning electron microscope photomicrographs, with some magnifications up to × 5000. The wall section of *Miliola saxorum* (fig. 13), for example, clearly cuts through the center of four pits. The second and fourth pit from the left side of the photomicrograph appear to have platforms located midway between the inner and outer walls of the chamber, or at the base of the pit. That portion of the pit seen on the exterior of the chamber is open; the inner portion is filled with shell material, which looks very much like a sieve plate or a small cribrate aperture (fig. 10). The platform at the base of the pit is more clearly defined in figure 15; the perforation openings on the inside of the chamber wall are shown in figure 14.

The perforations at the base of the platform in the pits are frequently arranged in a circular pattern adjacent to the exterior wall as shown in figures 7 and 28. The distribution of perforations between the pits can be seen below the cribrate aperture in figure 32.

The distribution of the perforations described above is characteristic of *Miliola saxorum, M. jacksonensis,* and the two species of *Tappanella.* The remaining species examined under a scanning electron microscope appear to have their perforations restricted to the pits in the chamber wall. This is true of *Miliola* sp. (fig. 23), *M. rolandi* (fig. 25), *Picouina mississippiensis* (fig. 35), *Neaguites inusitatus* (fig. 38), *N. byramensis* (fig. 40), *N. lamposus* (fig. 42), and *Texina ferayi* (fig. 46). *"Spiroloculina" imprimata* Cushman, borrowed from the U.S. National Museum, could not be subjected to scanning electron microscope study.

The proposed placement for the porcelaneous genera formerly included in the family Miliolidae is in the Fabularidae. Although specialized, it is part of the Miliolacea, and the oldest subfamily in the porcelaneous assemblage of genera.

Subfamily MILIOLINAE Ehrenberg, 1839

Emended Diagnosis (Loeblich and Tappan, 1964, p. 468): Wall simple; *may have cribrate aperture* (trematophore). Eocene-Oligocene.

Remarks: The small costate species of *Miliola* with relatively large pits for the size of the test, which occur in the Moodys Branch, Red Bluff and Byram formations in the Gulf Coastal Plain, and Damery and Grignon in France, have open, circular to semicircular apertures. Whether one presumes that the apertures were cribrate originally, or that they never had a cribrate aperture is inconsequential. No special consideration was given the aperture by Kaasschieter in 1961 (p. 161) when he wrote: "It is now doubtful that any *Quin-*

queloculina species with striae and pits occurs in the Eocene or Oligocene of France and Belgium." This statement can also be applied to all pitted Eocene and Oligocene *Quinqueloculina* species in the Gulf Coastal Plain.

Genus MILIOLA Lamarck, 1804

Type species: *Miliolites saxorum* Lamarck, 1804.

Emended Diagnosis: Test free, quinqueloculine chamber arrangement, latter chambers with floor; wall calcareous, perforate, and pitted; aperture simple or cribrate. Range: Eocene-Oligocene, North America and Europe.

Remarks: The two largest species of *Miliola* in the Gulf Coastal Plain, *M. saxorum* and *M. jacksonensis,* are well represented in the Moodys Branch Formation in Jackson, Mississippi. A smaller species, *M. rolandi,* n.sp., which occurs with the two large species above, ranges into the Red Bluff Formation (Oligocene). Present, but not abundant in the Byram Formation (Oligocene), is *M. byramensis.*

Quinqueloculina tessellata Cushman, described from the Byram Formation (not included in this report) probably should be assigned to the genus *Miliola.*

MILIOLA SAXORUM Lamarck

Figures 5-16.

Miliolites saxorum LAMARCK, Annales du Museum, vol. 5, no. 5, p. 352, 1804.

Quinqueloculina saxorum (Lamarck), D'ORBIGNY, Annales Sci. Nat., vol. 7, p. 301, no. 1, pl. 16, figs. 10-14, 1826.

Miliola saxorum Lamarck, CUSHMAN, U.S. Geol. Survey Prof. Paper 181, pp. 12, 13, pl. 3, figs. 1-3, 1935; BERGQUIST, Miss. Geol. Surv. Bull., no. 49, p. 25, pl. II, fig. 8, 1942; CUSHMAN and TODD, Contr. Cushman Lab. Foram. Res., vol. 21, pt. 4, p. 83, 1945; KAASSCHIETER, Inst. Royal Sci. Nat. Belgium, Memoir n. 147, p. 161, pl. IV, fig. 25-27, pl. V, fig. 1, 1961.

Emended Diagnosis: Test large, elongate, fusiform, quinqueloculine; chambers numerous, distinct, and pitted, chamber floor at least in the adult, estimated wall thickness of 0.023 mm to 0.03 mm; periphery normally rounded but occasionally with a slightly flattened surface; wall smooth, perforated, and with small, rounded pits arranged in oblique and longitudinally aligned rows, pits with none to several perforations at its base, which continue through the remaining portion of the chamber wall; aperture at the end of a very short neck, cribrate. Length 2.50 mm; diameter 0.60 mm.

Figured Specimens: LSU GM Nos. 10484-10487, 10489-10491, from the Moodys Branch Formation, Riverside Park, Jackson, Mississippi; LSU GM No. 10488, from the Lutetien at Damery, France.

Remarks. The type locality of *Miliola saxorum* is the Lutetien (Eocene) of the Paris Basin, France. Cushman's assignment of specimens from the Jackson (Eocene) of Mississippi to *Miliola saxorum* is reaffirmed.

Scanning electron microscope study of a *Miliola saxorum* specimen from the Moodys Branch Formation in Mississippi (figs. 9, 10) and a specimen from the Lutetien of Damery, France (figs. 11, 12), shows two picayunish differences between the two specimens. The Moodys Branch specimen is more pointed at the end opposite the aperture, and the aperture has a longer neck. These differences, however, are not considered important enough to recall Cushman's assignment of the Mississippian *Miliola* to the species *saxorum.*

MILIOLA JACKSONENSIS Cushman

Figures 17-19.

Miliola jacksonensis CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 9, pt. 1, p. 2, pl. 1, figs. 2, 3, 1933; CUSHMAN, U.S. Geol. Surv. Prof. Paper 181, p. 13, pl. 3, figs. 4-6, 1935; CUSHMAN and TODD, Contr. Cushman Lab. Foram. Res., vol. 21, pt. 4, p. 83, pl. 13, fig. 13, 1945; BANDY, Bull. Amer. Paleontology, vol. 32, no. 131, p. 22, pl. 2, figs. 6a-c, 1949.

Miliola cf. *jacksonensis* FRANKLIN, Journ. Paleontology, vol. 18, p. 308, pl. 45, fig. 6, 1944.

Emended Diagnosis: Test large, elongate, fusiform, quinqueloculine; chambers numerous, distinct, perforated, developing a chamber floor in the adult; periphery

rounded to very slightly angular; wall ornamented with thin, relatively high costae, aligned with the long axis of the test, not equally spaced; pits randomly distributed between costae; pits with one or more perforations, which continue from the base of the pit into the chamber; aperture at the end of a very short neck, cribrate. Length 2.00 mm; diameter 0.55 mm.

Figured Specimens: Topotypes, LSU GM Nos. 10492-10493, from the Moodys Branch Formation, Riverside Park, Jackson, Mississippi.

Remarks: Cushman made the following statement relative to *Miliola jacksonensis*, which he described originally from the Jackson Formation (now Jackson Group), in Jackson, Mississippi.

> In some respects it *[Miliola jacksonensis]* resembles the *Quinqueloculina parisiensis* of d'Orbigny, as figured by Terquem, but Fornasini's tracings of d'Orbigny's original plates show only the longitudinal costae with no sign of punctae.

Kaasschieter (1961, p. 182), in his memoir on the foraminifera of the Eocene of Belgium, considers Terquem's *Quinqueloculina parisiensis* a junior synonym of *Miliola disticha* (Terquem). The distinction made is that "the ornamentation of this species *[M. disticha]* is close to that of striated variants of *Miliola saxorum,* but typical specimens are more flattened." It appears, therefore, that *Miliola jacksonensis* Cushman does not resemble any European species.

Excerpts from the description of a *Miliola jacksonensis* reported by Bandy (1949) from the Yazoo Clay, Jackson, Eocene, at Little Stave Creek in Clarke County, Alabama, follows:

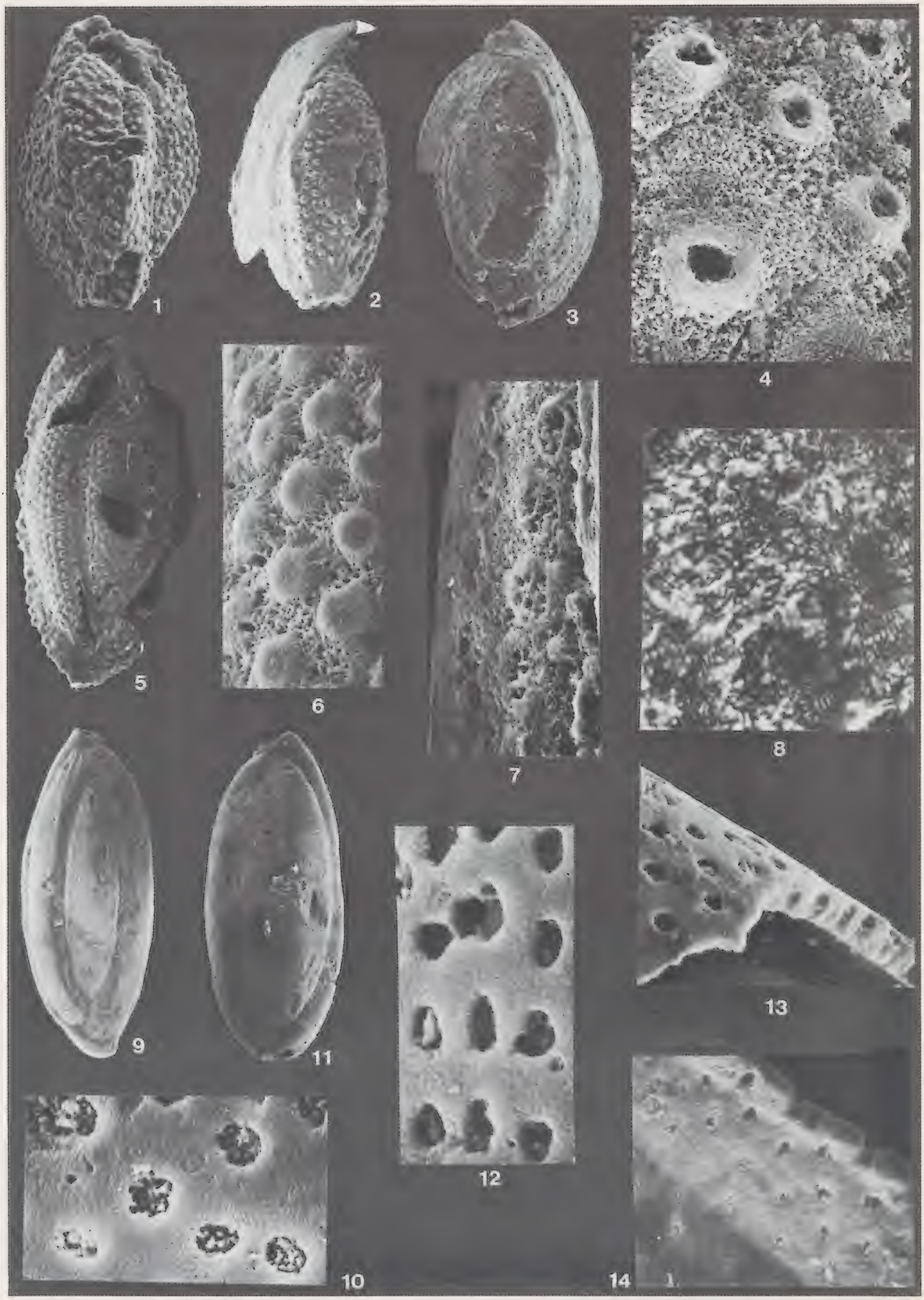
> . . . chambers with rounded backs; . . . ; wall silicious, white, surface ornamented with numerous fine longitudinal costae . . . Length 1.13 mm, diameter 0.37 mm.

Bandy's species, as illustrated, definitely has rounded chambers with costae so faint or fine that they do not project beyond the periphery of the chamber wall. Topotype specimens of *Miliola jacksonensis* have very pronounced, thin costae, which extend far enough beyond the periphery of each chamber to obscure partially the shape of the chamber. Also, the Alabama specimen, which is about half the length of the Mississippi specimens, is equally as close to the size of *Miliola rolandi;* and must have undergone diagenesis for its calcium carbonate test to be replaced with silica.

FIGURES

1-4. *Quinqueloculina tuberculata* Cushman and Todd
1. Weathered specimen, × 75 (LSU GM No. 10480)
2. Partially weathered specimen, × 100 (LSU GM No. 10481)
3. Unweathered specimen, × 75 (LSU GM No. 10482)
4. Weathered fragment, × 100 (LSU GM No. 10483)

5-14. *Miliola saxorum* Lamarck
5. Broken specimen showing knobs on interior chambers, × 63 (LSU GM No. 10484)
6. Enlargement of pits in figure 5 showing that the pits were filled when the floor above was secreted, × 1000 (LSU GM No. 10484)
7. Perforations at base of pits, × 500 (LSU GM No. 10485)
8. Polarizing microscope study of chamber wall, × *ca.* 2360 (LSU GM No. 10486)
9. Lateral view of specimen from Moodys Branch Formation, × 33 (LSU GM No. 10487)
10. Enlargement of pits, × 1000 (LSU GM No. 10487)
11. Lateral view of specimen from Lutetien at Damery, France, × 33 (LSU GM No. 10488)
12. Enlargement of pits, × 1000 (LSU GM No. 10488)
13. Section through chamber wall, × 200 (LSU GM No. 10489)
14. Interior of chamber wall, × 200 (LSU GM No. 10489)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MILIOLA BYRAMENSIS (Cushman)
Figures 20-22.

Quinqueloculina byramensis CUSHMAN, U.S. Geol. Surv. Prof. Paper 133, p. 54, pl. VIII, fig. 3, 1923.

Emended Diagnosis: Test quinqueloculine, approximately twice as long as broad, final chamber projects slightly beyond the penultimate chamber at both ends of test; chambers with broad, elevated costae longitudinally disposed, undermined by pits spaced at relatively regular intervals longitudinally, which produces eyelets in the costae; pits between costae are offset to those beneath the costae; periphery rounded; aperture on a slight neck. Length 0.3 mm to 0.4 mm.

Figured Specimens: LSU GM Nos. 10494-10495, from the Byram Formation at its type locality on the right bank of the Pearl River, east of Byram, Mississippi.

Remarks: Five specimens of *Quinqueloculina byramensis* Cushman were available from the H. V. Howe Collection, curated by the LSU Geoscience Museum. The most complete specimen, figure 20, was used for the lateral view; the best apertural view of two specimens (fig. 22), which appeared to have remnants of a cribrate aperture, in the photomicrograph proved to have only a highly polished apertural opening with no sign of cribrations.

Asssignment of this species to the genus *Miliola* is based upon the fact that the chambers are quinqueloculine, pitted and costate, and the species occurs in the Oligocene.

MILIOLA ROLANDI, new species
Figures 24-25.

Diagnosis: Test small, elongate, approximately 2.5 times as long as broad, quinqueloculine; base rounded, final chamber extends above the penultimate chamber; periphery rounded; chambers numerous, with low, broad ridges between rows of pits aligned with the long axis of the test; pits with a single perforation leading into the chamber; aperture at the end of a very short neck. Length of holotype 0.54 mm; breadth 0.20 mm.

Figured Specimen: Holotype, LSU GM No. 10497, from the Moodys Branch Formation, Riverside Park, Jackson, Mississippi.

Remarks: This species is similar to several of the small species of *Miliola* described in France and Belgium. The European forms appear to be much longer and narrower than *M. rolandi,* which has the general appearance of *M. jacksonensis. Miliola rolandi,* however, is much smaller; has broader and less elevated costae; and

FIGURES

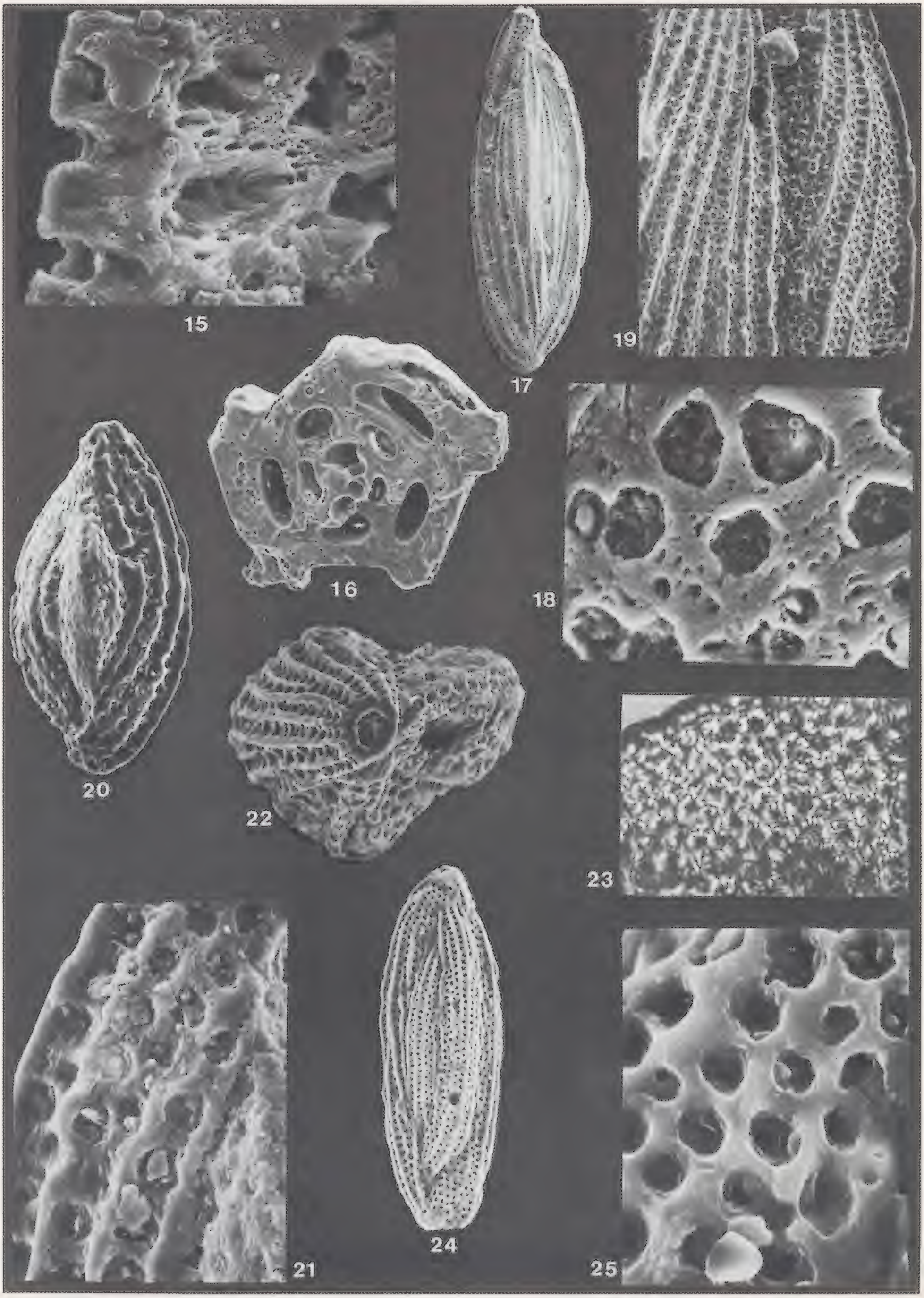
15-16. *Miliola saxorum* Lamarck
15. Wall section and interior of chamber showing perforations through the chamber wall, × 750 (LSU GM No. 10490)
16. Transverse section showing flat chamber floors around the perimeter of the test, × 175 (LSU GM No. 10491)

17-19. *Miliola jacksonensis* Cushman
17. Lateral view of topotype, × 33 (LSU GM No. 10492)
18. Enlargement of pits, × 1000 (LSU GM No. 10492)
19. Enlargement of costae and pits, × 80 (LSU GM No. 10493)

20-22. *Miliola byramensis* (Cushman)
20. Lateral view, figured specimen, × 150 (LSU GM No. 10494)
21. Eyelets in costae, × 500 (LSU GM No. 10494)
22. Apertural view, × 250 (LSU GM No. 10495)

23. *Miliola* sp.
Polarizing microscope study of chamber wall × *ca.* 2360 (LSU GM No. 10496)

24-25. *Miliola rolandi* Andersen, new species.
24. Lateral view of holotype, × 88 (LSU GM No. 10497)
25. Enlargement of pits, × 1000 (LSU GM No. 10497)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has a completely different wall structure. (See figures 18 and 25.)

The specimen destroyed, to produce the shell fragment shown in figure 23, was similar in size and shape to *Miliola rolandi*. The polarizing microscope study revealed, however, that the pits are smaller and more abundant than those in the wall of the holotype of *M. rolandi*, figure 25. It appears, therefore, that figure 23 (LSU GM No. 10496), is a wall fragment from an undescribed species of *Miliola* from the Moodys Branch Formation at Jackson, Mississippi.

Genus TAPPANELLA new genus

Type species: *Massilina jacksonensis* Cushman var. *punctatocostata* Cushman.

Diagnosis: Test free, elliptical to nearly round in outline, flattened, chambers one-half coil in length, early chambers quinqueloculine, later ones added to approximately 180° in a single plane, later chambers with a floor; wall calcareous, perforate, with a series of pits on the surface of the chambers; pits aligned with the long axis of the test; aperture cribrate. Range: Eocene.

Remarks: Luczkowska (1972, p. 350), in a revision of the Miliolidae from the Miocene of Poland, considers *Massilina* an invalid genus. The conclusion is that "*Quinqueloculina seminulum*, the genotype of *Quinqueloculina*, and *Quinqueloculina secans*, the genotype of *Massilina*, belong to the same taxonomic group," and that, "further investigations of a greater amount of material available will permit to find definite massiline forms of *Q. seminulum.*"

Be that as it may, it is safe to say that *Tappanella*, which has the identical chamber arrangement of *Massilina*, cannot suffer its fate. There is no apparent massiline stage in the ontogeny of *Miliola saxorum;* therefore, the genus *Tappanella*, the massiline form of the *Miliola* lineage, has no direct relationship with the type of *Miliola, M. saxorum* Lamarck.

Both *Heterillina* and *Tappanella* have a massiline chamber arrangement; however, neither the description nor the illustrated specimen of *Heterillina* in the *Treatise on Foraminiferida* by Loeblich and Tappan, (1964, p. 470, fig. 357, 7a-c) accommodates *Tappanella punctatocostata* (Cushman) with its pitted chambers, costae and perforate test.

This genus is named for Dr. Helen Tappan whose contributions to the field of micropaleontology are inestimable.

FIGURES

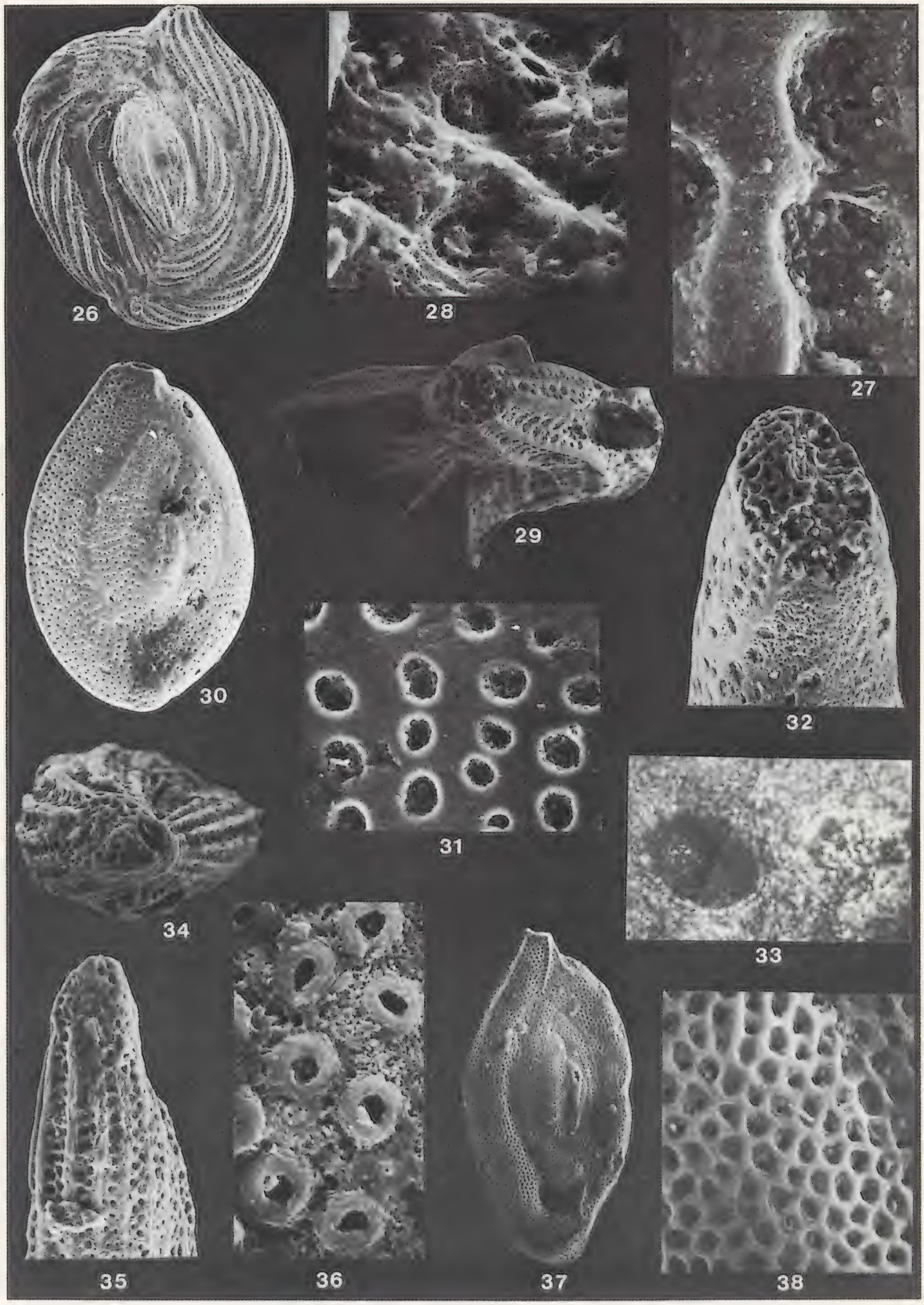
26-29. *Tappanella punctatocostata* (Cushman)
- 26. Lateral view of topotype, × 25 (LSU GM No. 10498)
- 27. Enlargement of pits, × 100 (LSU GM No. 10498)
- 28. Inside of test at base of pits, × 800 (LSU GM No. 10499)
- 29. Fragment of cribrate aperture, × 100 (LSU GM No. 10500)

30-33. *Tappanella jacksonensis* (Cushman)
- 30. Lateral view of topotype, × 30 (LSU GM No. 10501)
- 31. Enlargement of pits, × 500 (LSU GM No. 10501)
- 32. Apertural view, × 200 (LSU GM No. 10502)
- 33. Polarizing microscope study of chamber wall, × *ca.* 2360 (LSU GM No. 10503)

34-35. *Picouina mississippiensis* (Cushman)
- 34. Apertural view of topotype, × 300 (LSU GM No. 10504)
- 35. Side view of aperture, × 200 (LSU GM No. 10504)

36. *Neaguites* sp.
Weathered specimen, × 1000 (LSU GM No. 10505)

37-38. *Neaguites inusitatus* Andersen, new species.
- 37. Lateral view of holotype, × 150 (LSU GM No. 10506)
- 38. Enlargement of pits, × 1000 (LSU GM No. 10506)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TAPPANELLA PUNCTATOCOSTATA (Cushman)
Figures 26-29.

Massilina jacksonensis Cushman var. *punctatocostata* CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 9, pt. 1, p. 3, pl. 1, figs. 5, 6, 1933; CUSHMAN, U.S. Geol. Surv. Prof. Paper 181, p. 14, pl. 3, figs. 11-13, 1935; CUSHMAN and TODD, Contr. Cushman Lab. Foram. Res., vol. 21, pt. 4, p. 82, pl. 13, fig. 18, 1945; BANDY, Bull. Amer. Paleontology, vol. 32, no. 131, p. 25, pl. 2, figs. 8a-c, 1949.

Emended Diagnosis: Test broadly elliptical to nearly round, much compressed, periphery ranging from acute to slightly rounded depending on the position of the costae relative to the periphery; apertural end extending slightly beyond the penultimate chamber; wall calcareous, perforate; early chambers quinqueloculine, later ones added at 180° in a single plane with a chamber floor; surface ornamentated with low, thick costae oriented either parallel to the long axis of the chamber or cutting diagonally across the chamber, sutures difficult to discern because of the costae; costae separated by punctae, usually two offset rows; aperture at the end of a distinct but short neck, cribrate. Length of figured specimen 2.95 mm; breadth 2.05 mm.

Figured Specimens: Topotypes, LSU GM Nos. 10498-10500, from the Moodys Branch Formation, Riverside Park, Jackson, Mississippi.

Remarks: Over fifty adult topotypes of the type species of the new genus *Tappanella* were available at the time the emended diagnosis of the species was written. Not one of the specimens had a complete aperture, and only one (fig. 29) has fragments of a cribrate aperture in the apertural opening.

TAPPANELLA JACKSONENSIS (Cushman)
Figures 30-33.

Massilina jacksonensis CUSHMAN, Journ. Paleontology, vol. 1, p. 150, pl. 23, figs. 5, 6, 1927; CUSHMAN, U.S. Geol. Surv. Prof. Paper 181, pp. 13-14, pl. 3, figs. 7-10, 1935; CUSHMAN and TODD, Contr. Cushman Lab. Foram. Res., vol. 21, pt. 4, p. 82, pl. 13, fig. 17, 1945.

Massilina cf. *jacksonensis*. PURI, Florida Geol. Survey, Bull. 38, p. 108, pl. 3, figs. 2a,b, 1957.

Quinqueloculina tuberculata CUSHMAN and TODD, Contr. Cushman Lab. Foram. Res., vol. 21, pt. 4, p. 81, pl. 13, fig. 17, 1945.

Emended Diagnosis: Test broadly oval or elliptical, compressed, periphery ranging from acute to slightly rounded, ultimate chamber extends slightly beyond the penultimate chamber; wall calcareous, perforate with pits randomly distributed on the smooth chamber wall; early chambers quinqueloculine, later ones added at 180° in a single plane and with a chamber floor; sutures fairly distinct; aperture with a trematophore on a short neck. Length 1.40 mm; breadth 1.00 mm; thickness 0.20 mm.

Figured Specimens: LSU GM Nos. 10501-10503, from the Moodys Branch Formation, Riverside Park, Jackson, Mississippi.

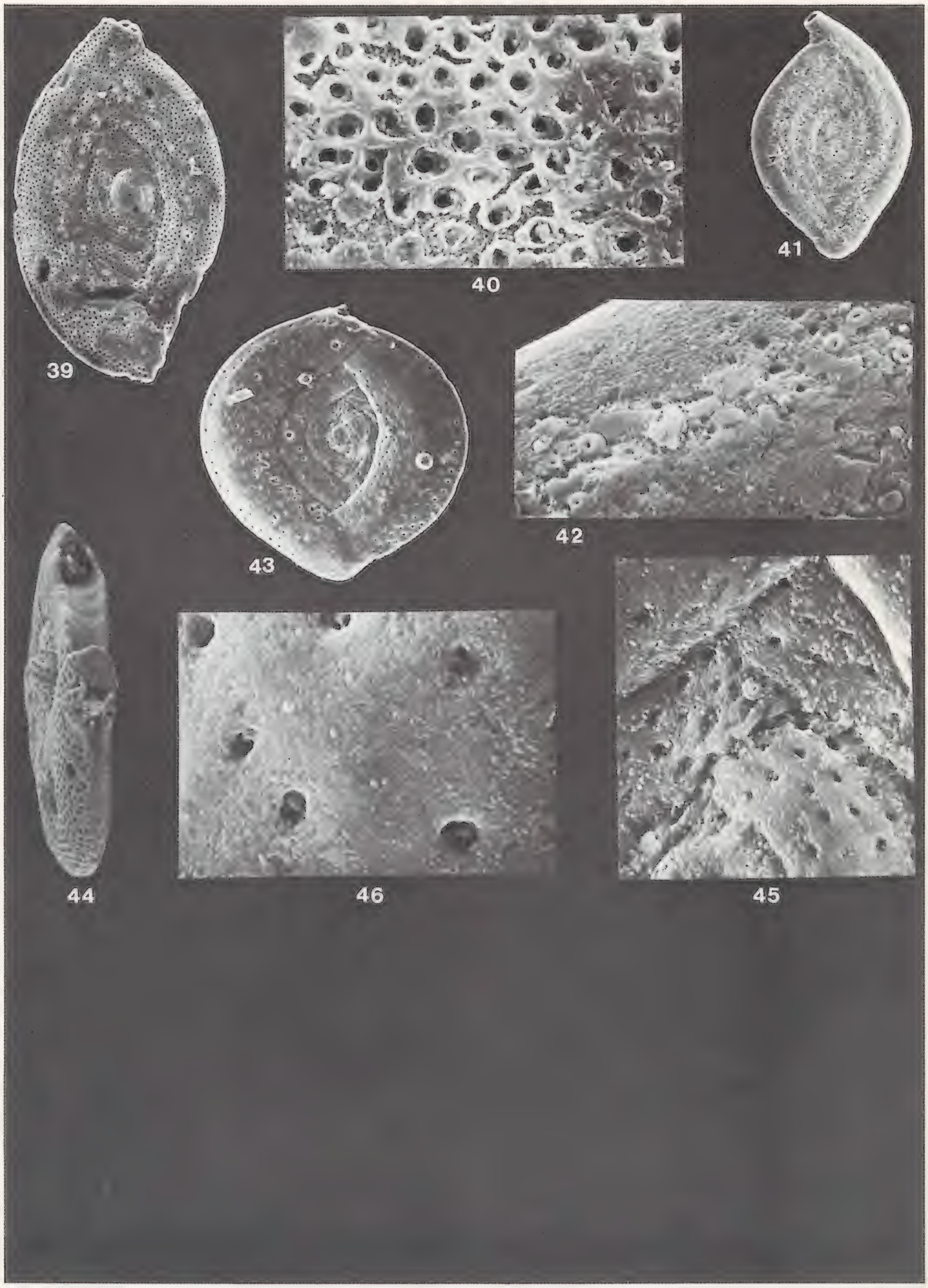
Remarks: Cushman described the foraminiferal species *Massilina jacksonen-*

FIGURES

39-40. *Neaguites byramensis* (Cushman)
- 39. Lateral view of topotype, × 113 (LSU GM No. 10507)
- 40. Enlargement of pores, × 1000 (LSU GM No. 10507)

41-42. *Neaguites lamposus* (Hussey)
- 41. Lateral view of figured specimen, × 100 (LSU GM No. 10508)
- 42. Enlargement of pores, × 1000 (LSU GM No. 10508)

43-46. *Texina ferayi* Andersen, new species
- 43. Lateral view of holotype, × 125 (LSU GM No. 10509)
- 44. Apertural view of paratype, × 225 (LSU GM No. 10510)
- 45. Enlargement of pores, × 1000 (LSU GM No. 10509)
- 46. Enlargement of pores, × 2500 (LSU GM No. 10509)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sis as a new species in 1927 and again in 1933. The descriptions were identical. The holotype for the 1927 *M. jacksonensis* USNM 369305, came from the Alazan clay, Rio Buena Vista, Vera Cruz, Mexico; the holotype for the 1935 *M. jacksonensis*, USNM 371529, came from the Jackson Group (Moodys Branch Formation) at Jackson, Mississippi.

Dr. Richard Cifelli, Curator of Paleobiology at the National Museum of Natural History, reported (personal communication) that the holotype of the 1927 *M. jacksonensis* is "non-existent." This leaves only the 1935 "holotype" upon which to base the species characteristics, providing the Commission on Zoological Nomenclature approves a petition that the 1927 name be suppressed because the holotype is no longer available, and that it would be nearly impossible to establish a neotype.

An angular *Quinqueloculina* in the Moodys Branch samples (fig. 3), satisfies the description of both *Quinqueloculina tuberculata* Cushman and Todd, 1945, and the quinqueloculine, microspheric stage of *Massilina jacksonensis* Cushman, 1935. For that reason, *Quinqueloculina tuberculata* Cushman and Todd is considered to be a junior synonym of the 1935 version of *Massilina jacksonensis* Cushman.

Genus PICOUINA new genus

Type species: *Triloculina mississippiensis* Cushman, 1935.

Diagnosis: Test free, triloculine chamber arrangement; wall calcareous perforate; chambers with a series of pits with single perforation extending into the chamber; aperture cribrate. Range: Oligocene.

Remarks: The genus *Picouina* differs from *Triloculina* in having a cribrate aperture, and a pitted and perforated test; and from *Austrotrillina* in having chambers with thin walls and a simple interior in contrast to the thick, alveolar wall of *Austrotrillina*.

This genus is named for Edward B. Picou, Jr., affiliated with Shell Offshore Incorporated, located in New Orleans, Louisiana.

PICOUINA MISSISSIPPIENSIS (Cushman)
Figures 34, 35.

Triloculina mississippiensis CUSHMAN, Contr. Cushman Lab. Foram. Res., vol. 11, pt. 2, p. 25, pl. 4, figs. 1a-c, 1935.

Emended Diagnosis: Test calcareous, perforate, small, elongate, triloculine; periphery broadly rounded; chambers fairly distinct, interior simple, semicircular in transverse section; final chamber extending well beyond the penultimate chamber, apertural end pointed; wall ornamented with numerous longitudinal costae extending the entire length of the chamber, very fine, circular, uniform sized pits in grooves between costae; sutures indistinct due to the costate ornamentation; aperture cribrate. Length 0.60-0.65 mm; breadth 0.15 mm; thickness 0.12 mm.

Figured Specimen: Topotype, LSU GM No. 10504, from the Byram Formation, about one foot above ledge under the expansion bridge on Pearl River, Byram, Mississippi.

Remarks: The description of *Picouina mississippiensis* (Cushman) was emended to accommodate the discovery of a single specimen with a cribrate aperture. Also, the research in this report justifies placing the genus in the perforate *Miliola* lineage.

Subfamily NEAGUITESINAE
Andersen, 1984, new subfamily

Diagnosis: Wall simple, chambers planispirally coiled, simple aperture.

Genus NEAGUITES, new genus

Type species; *Spiroloculina byramensis* Cushman.

Diagnosis: Test free, elliptical to round in outline, sides flattened to slightly concave on both sides of test; chamber arrangement planisphiral (proloculus followed by two chambers per volution, added at 180° in a single plane); wall calcareous, perforate with perforations oc-

cupying a series of pits on the surface of the chambers; aperture terminal, simple. Range: Eocene-Oligocene, North America.

Remarks: The chamber arrangement of *Neaguites* and *Spiroloculina* is identical. They differ in wall structure: *Spiroloculina* has a calcareous, porcelanous test; *Neaguites* is calcareous, perforate with pitted chambers. Neither a complete nor vestige of a cribrate aperture was present on any species studied.

The two species of *Neaguites, N. byramensis* and *N. lamposus,* appear to have chamber walls composed of three layers of calcium carbonate. The outer layer certainly, and the inner layer, in all probability, is denser than the middle layer. The erosion of the outer layer appears to be mechanical rather than chemical, as shown in figures 40 and 42, and the collar surrounding the pit is as well defined on *N. lamposus* as it is on weathered specimens of *Miliola saxorum,* except that the structure is smaller because the chamber wall is thinner.

Neaguites Andersen, new genus, is represented by *N. inusitatus,* n. sp., from the Red Bluff (Oligocene) Formation at Hiwanee Station, Mississippi; by *N. byramensis, N. imprimatus,* and *N.* sp. (fig. 36) from the type locality of the Byram (Oligocene) Formation in southern Mississippi; and by *N. lamposus* Hussey, from the Cane River (Claiborne, Eocene) Formation in Louisiana.

This genus is named for Dr. Theodor Neagu of the Paleontology Department, University of Bucharest, author of a Romanian Treatise on Micropaleontology, and contributor of an Upper Cretaceous foraminiferal study to the Louisiana Geological Survey's bulletin on the Geology of Natchitoches Parish, Louisiana, soon to be published.

NEAGUITES INUSITATUS, new species
Figures 37, 38.

Diagnosis: Test small, elliptical in outline, twice as long as broad; flat, megalospheric form with visible proloculus followed by two chambers per volution added in a single plane, microspheric form with early chambers at an angle to the plane of coiling; periphery rounded to broadly acute; aperture end extends beyond the penultimate chamber, final chamber frequently forming an eyelet at the base of the test by not remaining in juxtaposition with the preceeding chamber; chambers with a frosted appearance produced by its intensely pitted surface wherein there are perforations; aperture on a slight neck. Length of holotype 0.60 mm; breadth 0.30 mm.

Figured Specimen: Holotype, LSU GM No. 10506, from the Red Bluff Formation at Hiwanee Station, Mississippi.

Remarks: This pitted species was discovered by accident. A scanning electron microscope study was requested, because the test had a strange dull, frosted appearance not observed on any *Spiroloculina* species in the sample. The pits on the surface of the chambers are not visible under the normal magnifications used in a binocular microscope for studying foraminifera.

Those specimens with the eyelet at the base of the test can not be confused with any other species. When the eyelet is missing, the microspheric form looks a little like the calcareous, porcelaneous species *Massilina decorata;* the megalospheric forms are more elongate, and with a much more acute periphery than *Neaguites imprimita.*

NEAGUITES BYRAMENSIS (Cushman)
Figures 39, 40.

Spiroloculina byramensis CUSHMAN, U.S. Geol. Surv. Prof. Paper 129, p. 101, pl. 25, figs. 4a-b, 1922.

Emended Diagnosis: Test compressed, elliptical to broadly elliptical, perforated with perforations occupying a series of pits randomly distributed on the surface of the chamber; proloculus and initial chambers concealed in a coil positioned at an angle to the side of the test in the microspheric gen-

eration, latter chambers added at approximately 180° in a single plane, megalospheric generation with proloculus and initial chambers exposed on each side of test; latter chambers with floor; periphery of penultimate chamber rounded, final chamber slightly acute; aperture at the end of a short neck. Length of figured specimen 0.65 mm; breadth 0.51 mm.

Figured Specimen: Topotype, LSU GM No. 10507, from the type locality of the Byram Formation, right bank of Pearl River, east of Byram, Mississippi.

Remarks: Cushman's specimen figured in 1922 (pl. 25, figs. 4a-b), unfortunately not available to be reexamined, must have been the basis for the description of *Spiroloculina byramensis,* because the periphery is "squarely truncate" as originally diagnosed. Two specimens in the assemblage recovered from Byram Formation samples have squarely truncated peripheries formed by the chamber floors of the penultimate and final chambers. The perforated chamber wall, which forms an arch over the chamber floors, had been destroyed by erosion. It appears very likely that Cushman described a weathered specimen.

A paratype labeled "Cushman Collection 3703," a very poor example of a microspheric generation, is more complete than the specimen figured by Cushman in 1922 (pl. 25, figs. 4 a-b) and is clearly without a squarely truncated periphery. The final chamber has an acute periphery, the same as figure 39 in this report.

NEAGUITES LAMPOSUS (Hussey)

Figures 41, 42.

Spiroloculina lamposa HUSSEY, Journ. Paleontology, vol. 23, no. 2, p. 121, pl. 26, fig. 6, 1949.

Emended Diagnosis: Test small, elliptical in outline, compressed, slightly biconcave; chambers pitted, spiroloculine (proloculus followed by two chambers per volution added at 180° in a single plane), perforations restricted to pits in chamber wall; periphery rounded; aperture terminal on a short, constricted neck. Length of figured specimen 0.45 mm; breadth 0.28 mm.

Figured Specimen: LSU GM No. 10508, from an outcrop in a tributary to Limekiln Bayou, Section 3, T8N, R8W, approximately 7 miles west of Natchitoches, Louisiana.

Remarks: This is the earliest occurring species of the genus *Neaguites* in the Gulf Coastal Plain. A contemporary species, also with a spiroloculine chamber arrangement, *Texina ferayi,* occurs in an intensely glauconitic unit in the Weches Formation in Texas as does *Neaguites lamposus* from the Cane River Formation in Louisiana. It is strange that the two species, both in the Claiborne Eocene, never occur together in either the Weches or Cane River formations.

NEAGUITES IMPRIMATUS (Cushman)

Spiroloculina imprimata CUSHMAN, U.S. Geol. Surv. Prof. Paper 129-E, p. 101, pl. 25, figs. 3a-b, 1922.

Remarks: The holotype (Cushman Collection 25520) and a paratype (Cushman Collection 3771) were examined. If the size of the pits on the chamber walls is consistent within a species, which certainly is true in *Miliola saxorum,* then the two types examined are not the same species. The holotype has extremely small pits on the chamber walls, so small that they could be missed in binocular microscope examination. The pits on the paratype are large enough to be seen with the binocular microscope; not as readily as those of *S. byramensis,* but nevertheless are discernible.

Also, Cushman's description of the holotype does not apply to the paratype. The former has chambers "of the last-formed coil failing to extend to the base of the preceeding chamber, leaving a gap."

Not a single specimen was recovered from the Byram Formation samples, which could be assigned to this species. Examination of the types, however, reveals that both belong to the genus *Neaguites*. A more thorough study with additional specimens is needed to determine the relationship of the holotype to the paratype of *Spiroloculina imprimata* Cushman.

Subfamily TEXININAE Andersen, 1984, new subfamily

Wall with adventitious material, planispirally coiled, aperture cribrate.

Genus TEXINA, new genus

Type species: *Texina ferayi*, new species.

Diagnosis: Test free, wall with adventitious material, rounded outline, sides flattened; planispiral chamber arrangement with two chambers per volution; wall calcareous, pitted, with perforations occupying the pits on the surface of the test; aperture cribrate.

Remarks: This genus is named for the State of Texas, wherein the type species was recovered, and to which it appears to be restricted.

TEXINA FERAYI, new species
Figures 43-46.

Spiroloculina smithvillensis FERAY, nomen nudum, Dissertation, University Wisconsin, 1948.

Diagnosis: Test calcareous with adventitious material, spiroloculine chamber arrangement (proloculus followed by two chambers per volution), nearly round in outline, much compressed; periphery acute; apertural end nearly flush with periphery; chambers embracing, pits randomly distributed over unornamented chambers with apparently one to two perforations in each pit; aperture at the end of a short neck, cribrate. Length of holotype 0.48 mm; breadth 0.45 mm.

Figured Specimen: Holotype, LSU GM No. 10509; paratype LSU GM No. 10510, from the Weches Formation outcrop on the Colorado River at Smithville, Texas.

Remarks: Spiroloculina smithvillensis Feray, nomen nudum, and *Texina ferayi* Andersen, n. sp., are considered to be the same species because *S. smithvillensis* was the only spiroloculine species recovered by Feray in the samples studied for his dissertation in 1948 and this is the only spiroloculine species present in the Weches samples studied for this report. The two species must be the same, although the specimen selected by Feray as a "holotype" is more embracing than the holotype selected herein, or any paratype observed.

The photomicrograph of *Texina ferayi* (fig. 45), revealed the presence of white particles associated with the chamber wall. At the magnification in figure 45, × 2000, it would have been presumptious to make a positive statement relative to the relationship between the chamber wall and extraneous particles. Photomicrograph figure 46 at × 5000 magnification, however, provided the proof that the white particles are embedded in the chamber wall and, of equal importance, that the perforations are restricted to the pits. Unfortunately, the × 5000 magnification did not make it possible to identify the particles embedded in the test. They are relatively uniform in size and apparently composed of the same material. The question - were the particles selected or adventitious? - may be important at the species level.

IV. DISCUSSION

The Enigmatic Knobs on Quinqueloculina tuberculata *Cushman and Todd.* Weathering of a pitted chamber wall should be indiscriminate in that the removal of calcium carbonate would be at the same rate in the pits as on the surface of the test between pits (fig. 3). It is illogical, therefore, for the pits in *Quinqueloculina tuberculata* to become a rounded knob when weathered (figs. 1, 2).

A partial solution to this enigma lies in the fact that two weathered specimens, *Q. tuberculata* (fig. 4), and an unidentified species of *Neaguites* (fig. 36), and a freshly broken specimen of *Miliola saxorum* (fig. 5), which exposes the inner chambers of the test, all have knobs. Figures 4 and 36 show that a collar surrounding each pit is denser then the rest of the material in the test. Obviously, these collars were strong enough to withstand the erosional process, which destroyed the intervening, softer material between the pits. The knobs, therefore, were produced by differential weathering. The knobs in figure 5, how-

ever, can not be the product of differential weathering, because the chambers exposed in the photomicrograph were covered and protected by the floors of the overlying chambers. The collar surrounding the pit was strong enough to hold onto the inner membrane of the chamber wall; the intervening, softer material in the chamber wall was removed with the overlying chamber floor.

It appears that either the composition, structure, or density of the collar surrounding the pits is responsible for producing the knobs on the chamber wall. Concentrating a sufficient number of knobs for an x-ray defraction study was conceivably possible but not with the laboratory equipment available; the polarizing microscope study contributed nothing to a study of the microstructure of the wall. Only the scanning electron microscope showed that the collar is denser than the intervening shell material; however, it gave no clue as to how this was accomplished.

Environmental Implications. The Lutetien of the Paris Basin must be regarded as the model environment in which the genus *Miliola* thrived, because more species are recognized in Europe than in the Gulf Coastal Plain and their distribution is more widespread. The Moodys Branch Formation is probably as widespread as the Lutetien; however, the genus *Miliola* is restricted, apparently, to Mississippi, and Alabama.

The foraminiferal assemblages recovered from the Damery and Grignon, France, samples consisted of an abundance of species from families known to live in a warm, clear water, shallow marine environment. The marker families present are: Alveolinidae, Asteigerinidae, "Miliolidae," Penerolipidae, and Polymorphinidae. Pelagic families were missing. This Lutetien environmental assemblage could best be duplicated in the calcareous deposits of Florida, from which one species of the *Miliola* lineage has been questionably referred to *Tappanina jacksonensis* (Cushman).

The Moodys Branch foraminiferal assemblage contains some of the genera from the shallow water families in the Lutetien, as does the Red Bluff and Byram Formations of the Oligocene. The Weches Formation is least like the Lutetien; however, its sediment is also considered to have been deposited in shallow water.

The common denominator in all sample studied is that they represent deposition in shallow water. It appears, therefore, that the foraminifers, with which members of the *Miliola* lineage are associated, prefer a shallow, warm water, marine environment.

Biostratigraphic Markers. The geographical distribution of outcrops in the Gulf Coastal Plain, from which the genus *Miliola* has been reported, is restricted to southern Mississippi and Alabama; the stratigraphic range is from the Moodys Branch Formation of the Jackson Eocene, to the Byram Formation near the top of the Oligocene. The size of the species within the genus ranges from 2.0 mm in length in the Moodys Branch Formation to less than 1.0 mm in length in the Byram Formation.

The foraminiferal assemblage varies from outcrop to outcrop in the Moodys Branch Formation in its lateral distribution from Mississippi into Texas. *Miliola saxorum* and the two species of *Tappanella* have been reported only from the Moodys Branch Formation, and only from those outcrops in the vicinity of Jackson, Mississippi. Any one of the three species above recovered from the subsurface in the southern part of Mississippi is proof positive that the age of the sediment, from which the species are recovered, is basal Jackson.

Two of the remaining genera described herein, *Picouina* and *Neaguites*, are too rare to be considered good marker fossils. *Picouina* has been reported only from the Byram Formation at its type locality; *Neaguites* ranges from the Cane River Formation in Louisiana to the Byram Formation in Mississippi.

The genus *Texina* is abundant enough to be a good marker fossil for the Weches Formation in Texas.

V. ACKNOWLEDGMENTS

This study was made possible by students and friends, who supplied the binocular microscope needed to search the samples for the specimens used in this report; by Harry L. Roland, Jr., of Andersen & Roland, Inc., who approved the use of corporate funds for photomicrographs and other necessary expenses; and by the Louisiana Geological Survey staff, who permitted me to use their polarizing microscope.

Dr. Richard Cifelli, Curator of the Department of Paleobiology at the National Museum of Natural History contributed time and energy answering numerous questions related to foraminiferal species in the U.S. Museum of Natural History and allowed me to observe some of the specimens redescribed in this study.

Dr. Willem van den Bold, Professor of Geology at Louisiana State University, was consulted frequently in the preparation of this report, provided pertinent publications, and served as the principal critic of the revised manuscript.

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I especially wish to thank Richard Cifelli, Edward B. Picou, Jr., and Hubert C. Skinner for their time spent reviewing this paper, and their suggestions, which have improved the contents immeasurably.

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EVALUATION OF THE FORAMINIFERAL GENERA *CONGLOBATOIDES* AND *CONGLOPHRAGMIUM*

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Saidova (1981), in her systematic review of Cainozoic benthic foraminifera, established the genus *Conglobatoides* with *Trochammina conglobata* Brady, 1884, as type species. The same species had, however, been earlier selected by Bermudez and Rivero (1963) as the type species for their new genus *Conglophragmium*. The species *Trochammina conglobata* Brady, 1884, should be retained in the genus *Conglophragmium* Bermudez and Rivero (ICZN Art. 67e) and the genus *Conglobatoides* Saidova recognized as a junior objective synonym of *Conglophragmium* Bermudez and Rivero (ICZN Art. 61b).

We thank W. H. Akers for reading this note, S. Kirsch and K. L. Finger for technical assistance, and Chevron Oil Field Research Company for publication permission.

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STATUS OF THE FORAMINIFERAL SUBGENUS *MICROFASCIOLITES* GAEMERS, 1978

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Gaemers (1978) systematically evaluated alveolinid specimens obtained from the Ager Formation, Tremp Basin, Spain, and established the new subgenus *Microfasciolites* with *Alveolina boscii* (Defrance *in* Bronn, 1825) as type species. The same species had, however, been earlier selected by Defrance *in* Bronn (1825) as type species of the genus *Oryzaria* (as *O. boscii)*, which was established for specimens obtained from a fossil calcareous sand in the Oise Valley, France. Loeblich and Tappan (1964) regarded *Oryzaria* Defrance *in* Bronn, 1825, as a junior subjective synonym of *Fasciolites* Parkinson, 1811. However, the species *Oryzaria boscii* Defrance *in* Bronn, 1825, must be retained in the genus *Oryzaria* Defrance *in* Bronn (ICZN Art. 67e) and the subgenus *Fasciolites (Microfasciolites)* Gaemers recognized as a junior objective synonym of *Oryzaria* Defrance *in* Bronn (ICZN Art. 61b).

I acknowledge S. Kirsch for technical assistance and Chevron Oil Field Research Company for publication permission.

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October 31, 1984

PLANKTIC FORAMINIFERA AND CALCAREOUS NANNOPLANKTON BIOSTRATIGRAPHY OF THE NEOGENE OF MEXICO PART II – LOWER PLIOCENE

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I. ABSTRACT

Six outcrop localities in the Isthmus of Tehuantepec, Mexico, are assigned to the Lower Pliocene Zones N. 18 or N. 19 on the basis of concurrent range zones of planktic foraminifera and calcareous nannofossils. Beds at one of the localities have been referred to the Encanto "Formation" by Mexican geologists. Microfossil lists for the localities follow the taxonomic procedures of Kennett and Srinivasan (1983) or Haman *et al.* (1980), differing only when inconsistent with the experience or interpretations of this writer. Illustrations have been included for taxa that were not identified from the Middle Pliocene of Mexico in this series (Akers, 1979).

II. INTRODUCTION

This is the second part in a series of reports on calcareous nannofossils and planktic foraminifera from some Neogene beds of Mexico. Part 1 (Akers, 1979) and the addendum to Part 1 (Akers, 1981) dealt

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KENNETH L. FINGER, Chevron Oil Field Research Company, La Habra, California

with the Middle Pliocene "formations" (Neogene Zone 20) to which the names Agueguexquite, Filisola, Concepcion Superior, and Concepcion Inferior have been applied.

The introductory remarks for Part 1 of this series are also appropriate for Part 2 and should be reviewed for the objectives of documenting the calcareous microplankton of the Mexican Tertiary. In general, it may be repeated that the fossil groups considered in this project afford assignment of the Mexican beds to transoceanic Neogene Zones 18 and 19 (Blow, 1969; Berggren and Van Couvering, 1974) and that the proposed geochronologic revisions for these sections are necessary, if Mexican successions are to conform stratigraphically with the rest of the world.

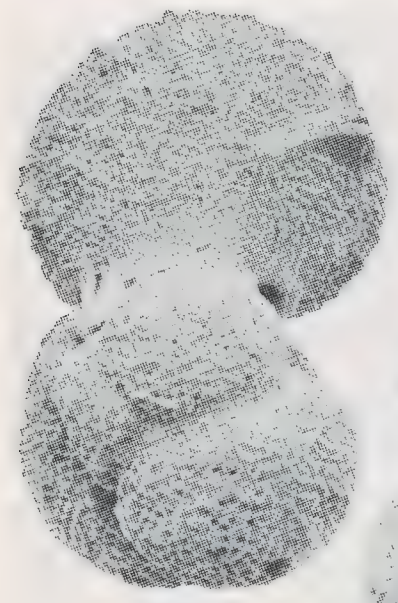
The stratigraphic ranges of index species, as determined by data from the Deep Sea Drilling Program, as well as data from land based sections, are the bases of chronologic assignments. Unlike material from tropical deep sea sites, the Mexican outcrops do not contain a high diversity of planktic microfossils. The forms recorded herein were found only after relatively prolonged microscopic examination, rather than after only a few minutes, as in the case of highly fossiliferous material from deep sea cores. Thus, chronostratigraphic interpretations are offered for assemblages that are less than ideal for this purpose.

Several index fossils are illustrated herein as well as in the previous report (Akers, 1979) on the Middle Pliocene of Mexico. In general, however, the plan was to include taxa not figured in Part 1. Useful species for chronostratigraphic purposes are charted in Figure 2 with their respective occurrences in tropical Neogene zones recognized by the Deep Sea Drilling Program.

PLATE 1

Figures

1. *Globigerina* cf. *G. incisa* (Bronnimann and Resig)
   Locality TU 1153
   a. Edge view, −107
   b. Umbilical view, ×105
   c. Spiral view, ×100
2. *Globigerina nepenthes* Todd
   Locality TU 1323
   a. Spiral view, ×135
   b. Edge view, ×135
   c. Umbilical view, ×135
3. *Globigerina* cf. *G. nepenthes* Todd, juvenile(?)
   Locality TU 1324
   a. Umbilical view, ×225
   b. Spiral view, ×230
4. *Globigerina calida* (Parker)
   Locality TU 1153
   a. Edge view, ×72
   b. Umbilical view, ×70
   c. Spiral view, ×72
5. *Globigerina glutinata* (Egger)
   Locality TU 1323
   a. Edge view, ×145
   b. Umbilical view, ×140
   c. Spiral view, ×145
6. *Globigerina conglobatus conglobatus* (Brady)
   Locality TU 1153
   a. Spiral view, ×65
   b. Umbilical view, ×62
   c. Edge view, ×65



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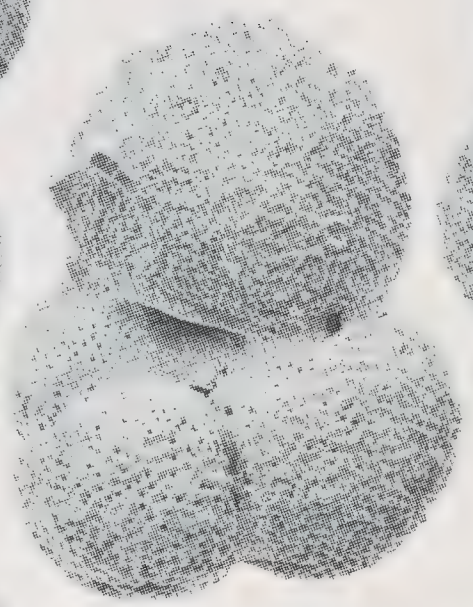

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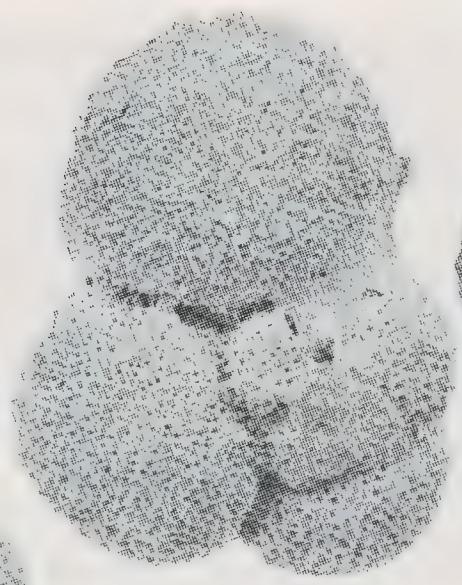

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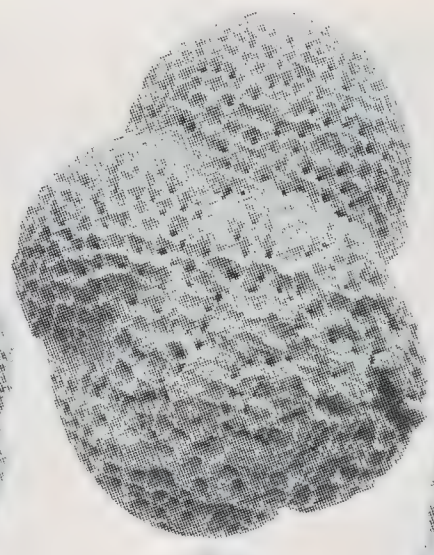

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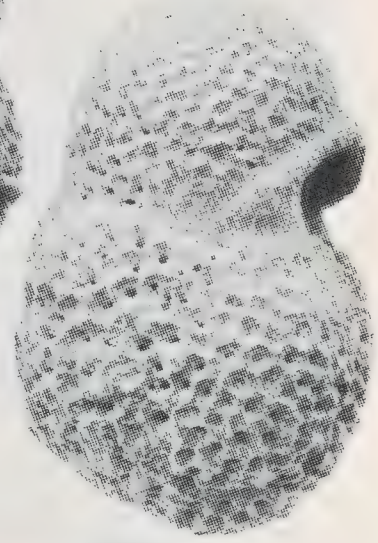

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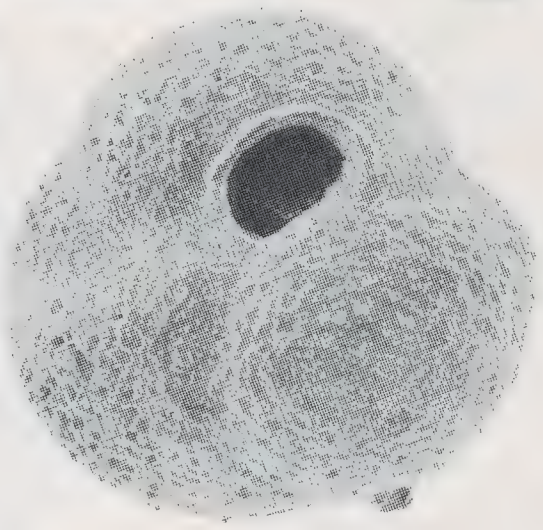

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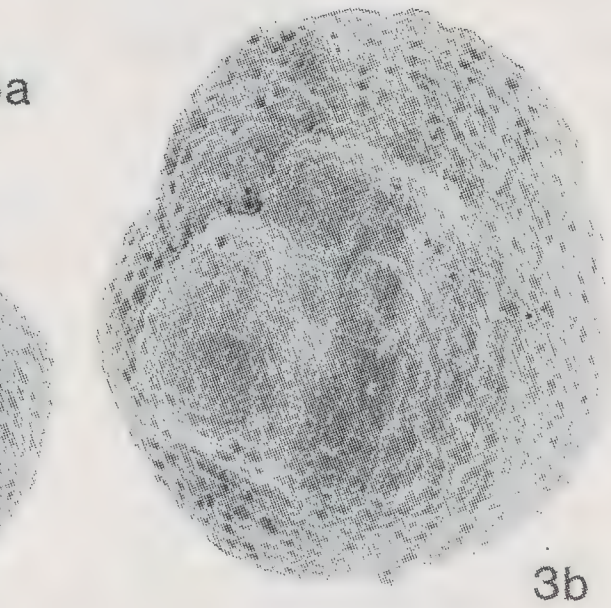

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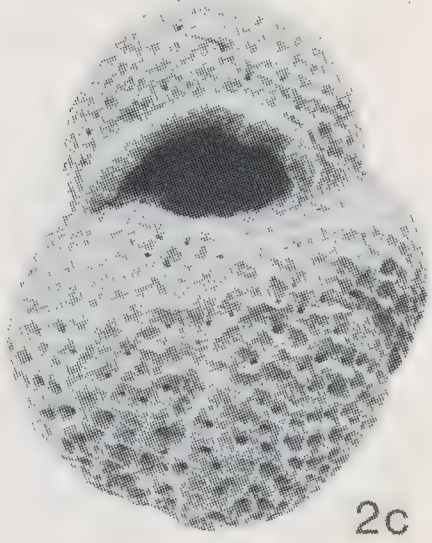

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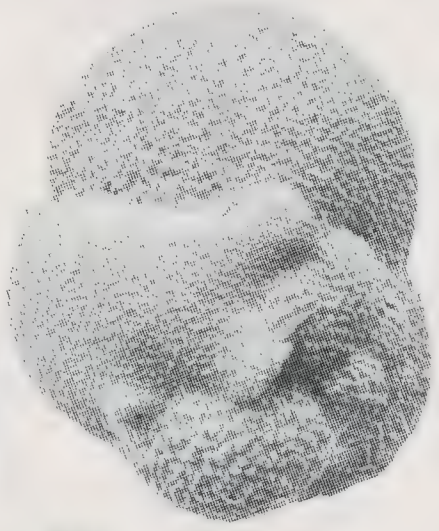

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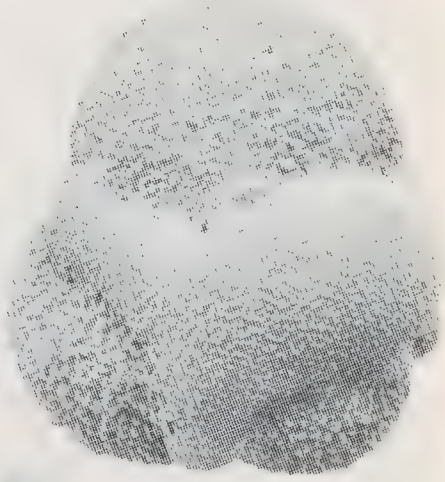

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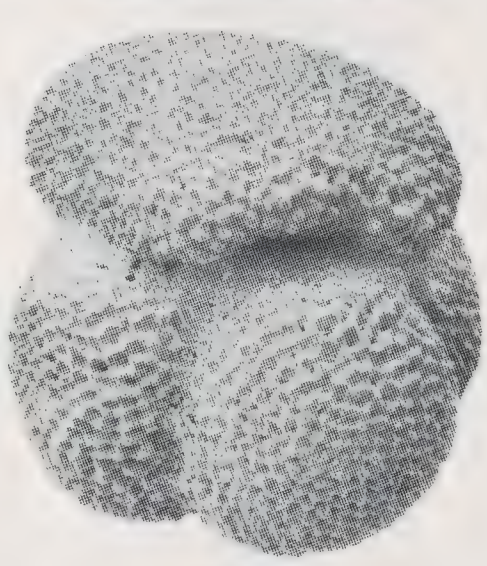

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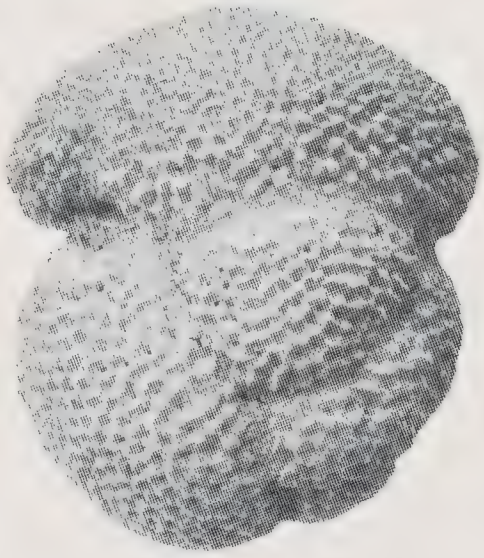

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PLATE 1

III. ACKNOWLEDGMENTS

Thanks go to the editorial committee: Drew Haman and Kenneth L. Finger, Chevron Oil Field Research Company. The Mexican sites would not have been studied, and the manuscript would not have been written without the field guidance and the constant encouragement of Emily and Harold Vokes. Figure 1, showing the location of five of the six Lower Pliocene sites, is the contribution of Emily Vokes. Chevron USA (Eastern Region) supported the research and permission to publish was given by Chevron Oil Field Research Company.

IV. BIOSTRATIGRAPHY, NEOGENE ZONES 18 AND 19

A. LOCALITY TU 1144

An unnamed formation is exposed at locality TU 1144 in roadcuts on Mexico Highway 185, about 42 km south of Acayucan, state of Veracruz. Beds three to four meters in thickness are exposed in the area approximately 3 km due east of Istal (formerly Santa Rosa), Veracrux (see Perrilliat, 1972, p. 10). The lithology is a hard, calcareous clay of uniform buff color, and the small amount of residue on a No. 200 U.S. Standard Series Sieve consists of the tests of foraminifera and aggregates of limonite. No quartz sand was observed in the residue. Calcareous nannofossils are so abundant in the clay that the material may be termed a calcareous nannofossil lutite. Samples were collected by H. E. and E. H. Vokes and W. H. Akers, 1979.

The following planktic foraminifera were found in residues from TU 1144:

Biorbulina bilobata (d'Orbigny)
Candeina nitida nitida d'Orbigny
Globigerina bulloides bulloides d'Orbigny
G. decoraperta Takayanagi and Saito
G. nepenthes Todd
Globigerinita glutinata (Egger)

PLATE 2

Figures

1. *Globigerinoides mitra* Todd
   Locality TU 1144
   a. Side view, ×90
   b. View of primary aperture, ×90
   c. Side view showing supplementary aperture, ×90
2. *Globorotalia (Truncorotalia) crassiformis* (Galloway and Wissler)
   Locality TU 1153
   a. Umbilical view, ×110
   b. Edge view, ×110
   c. Spiral view, ×115
3. *Globorotalia (Menardella) miocenica* Palmer
   Locality TU 1144
   a. Umbilical view, ×105
   b. Edge view, ×105
   c. Spiral view, ×105
4. *Globorotaloides hexagona hexagona* (Natland)
   Locality TU 1153
   a. Spiral view, ×147
   b. Umbilical view, ×150
   c. Edge view, ×152
5. *Globorotaloides hexagona hexagona* (Natland)
   Locality TU 1332
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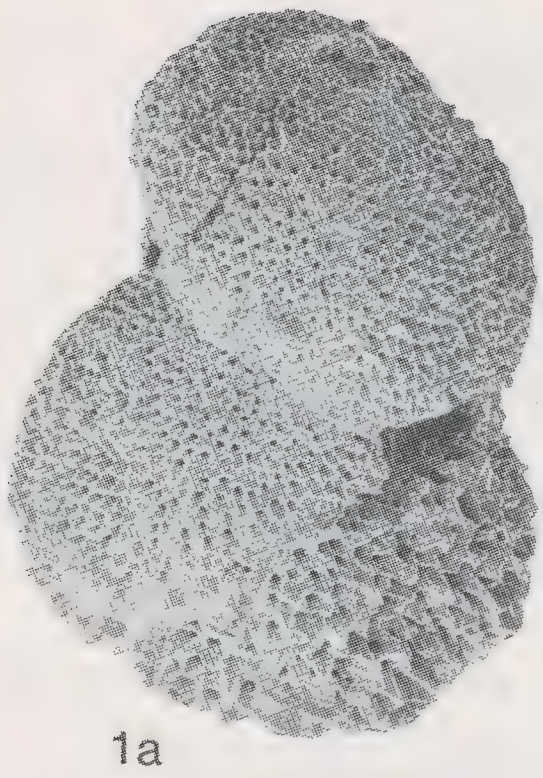
   b. Umbilical view, ×147
   c. Edge view, ×150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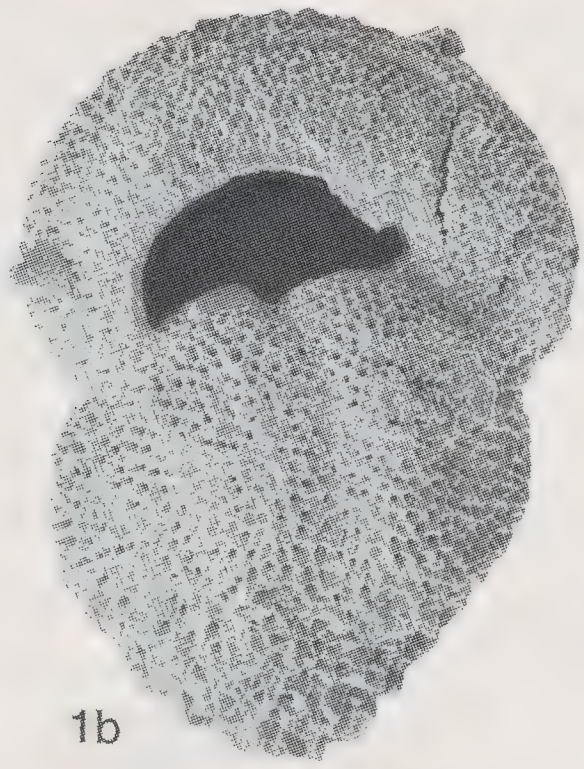
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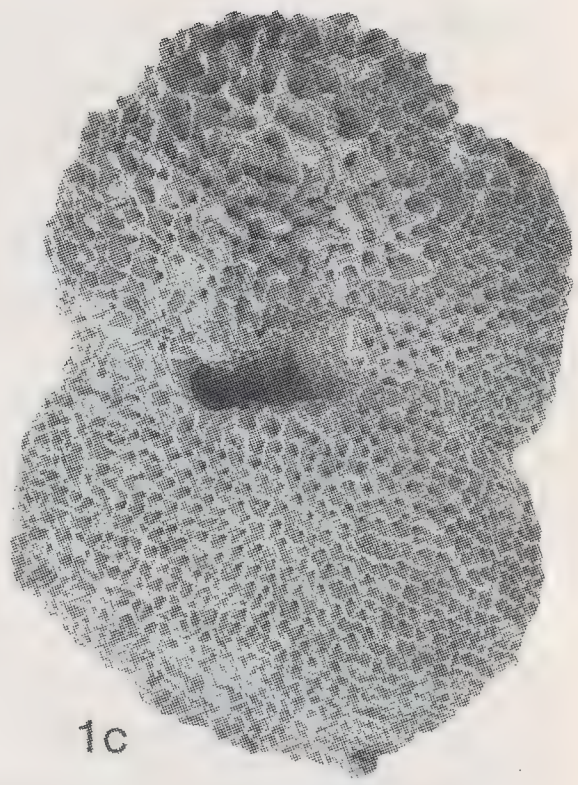
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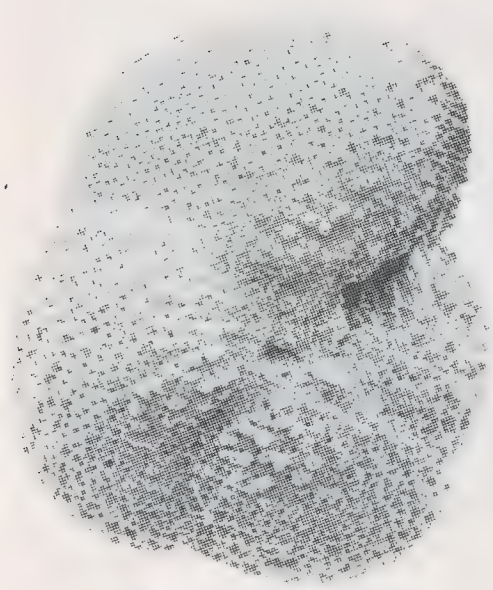
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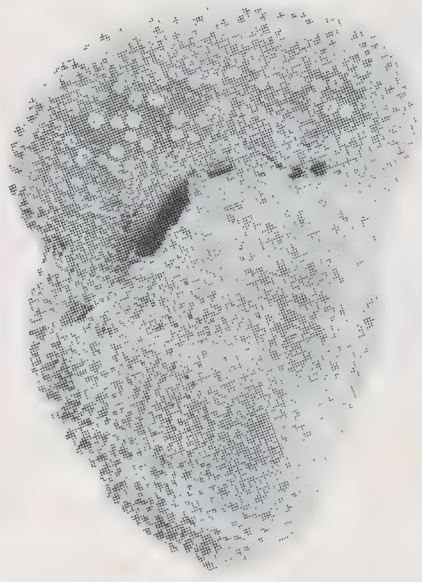
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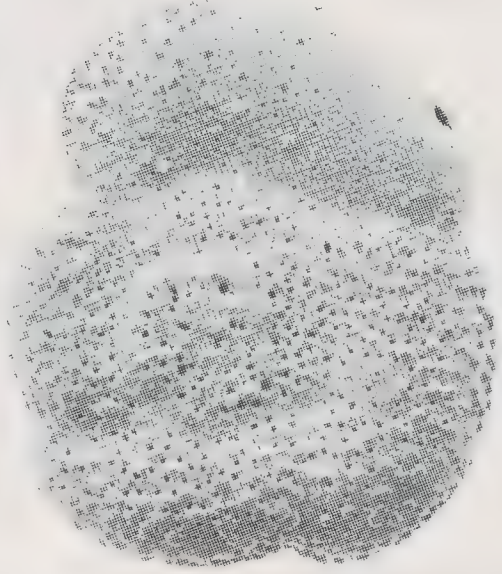
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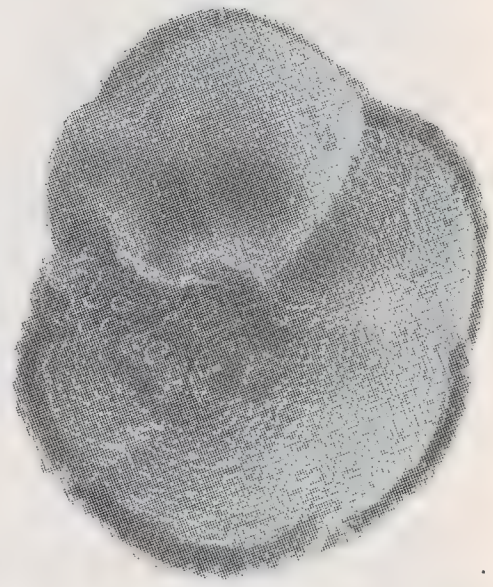
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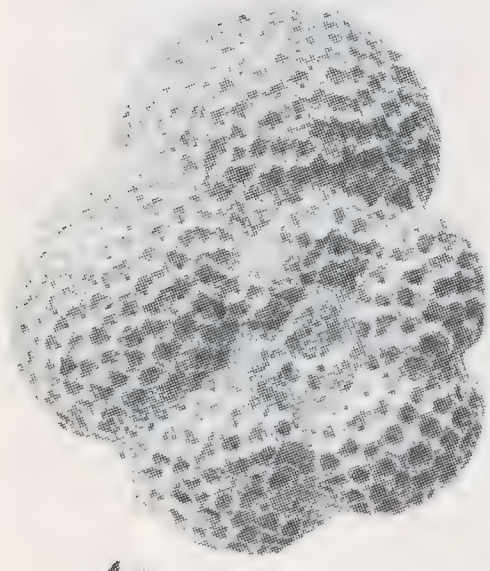
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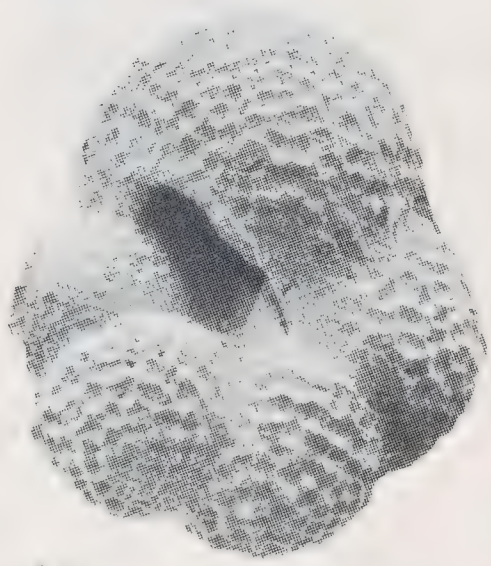
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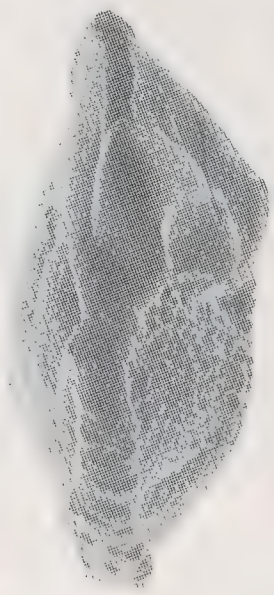
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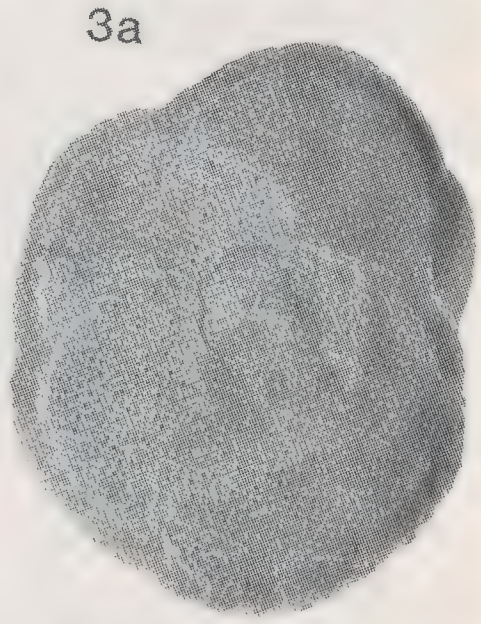
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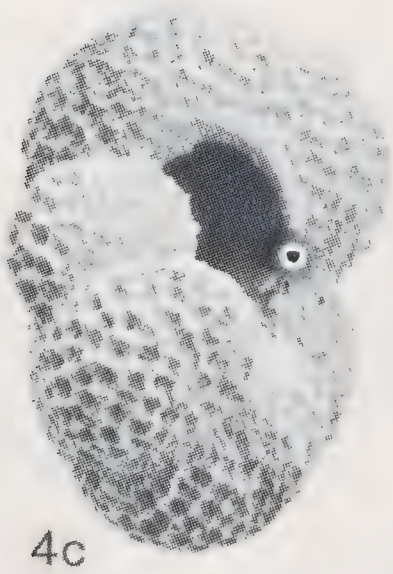
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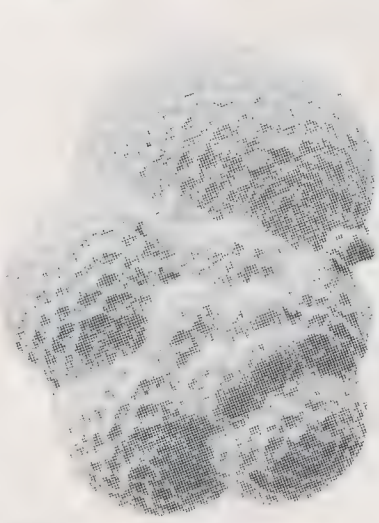
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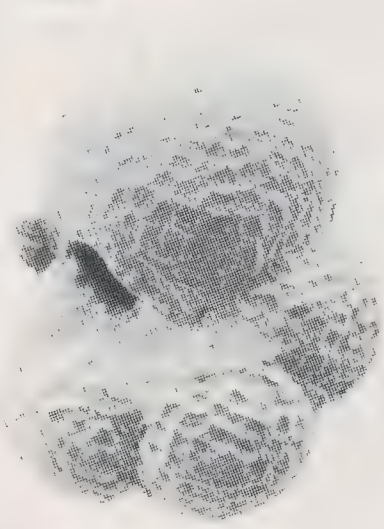
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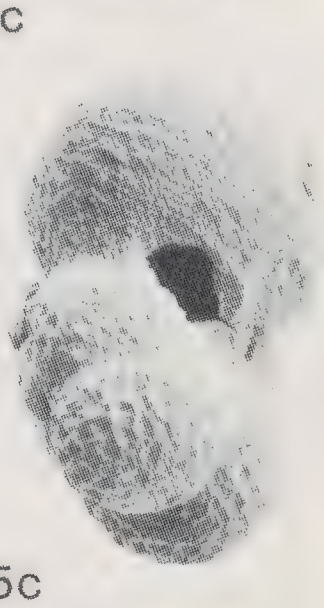
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PLATE 2

Globigerinoides conglobatus conglobatus (Brady)
G. mitra Todd
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa Bolli
G. venezuelana (Hedberg)
Globorotalia (Obandyella) margaritae Bolli and Bermudez
G. cf. *G. (O.) margaritae* Bolli and Bermudez
G. (Menardella) cultrata limbata (Fornasini)
G. (M.) miocenica Palmer
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Neogloboquadrina acostaensis (Blow)
N. humerosa (Takayanagi and Saito)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiie
Sphaeroidinellopsis seminulina seminulina (Schwager)
S. subdehiscens subdehiscens (Blow)
Turborotalita humilis (Brady)

The following calcareous nannoplankton have been identified from TU 1144:

Cyclicargolithus doronicoides (Black and Barnes) Wise
C. pelagicus (Wallich) Schiller
C. sp.
Cyclococcolithina leptopora (Murray and Blackman) Wilcoxon
Discoaster brouweri Tan
D. pentaradiatus Tan
D. surculus Martini and Bramlette
D. sp.
Discolithina sp.
Emiliania annula (Cohen) Bukry
Gephyrocapsa reticulata Nishida
Helicopontosphaera sp.
Reticulofenestra pseudoumbilica (Gartner) Gartner
Sphenolithus abies Deflandre
Syracosphaera sp.
Umbilicosphaera mirabilis Lohmann

Geologic Age of Beds at TU 1144 and Correlation with Other Strata

The concurrence of *Globigerinoides mitra* and *Globigerinoides conglobatus conglobatus* indicates a position in Lower Pliocene, Zone N. 18. *Globigerinoides mitra* became extinct by the end of that time, and *Globigerinoides conglobatus conglobatus* first appeared near the base of Zone N. 18 (Figure 2).

PLATE 3

Figures
1. *Pulleniatina primalis* Banner and Blow
   Locality TU 1153
   a. Umbilical view, ×100
   b. Edge view, ×95
   c. Spiral view, ×98
2. *Sphaeroidinellopsis seminulina seminulina* (Schwager)
   Locality TU 1323
   a. Edge view, ×97
   b. Spiral view, ×91
   c. Umbilical view, ×91
3. *Sphaeroidinellopsis seminulina seminulina* (Schwager)
   Locality TU 1144
   a. Umbilical view, ×69
   c. Spiral view, ×69
4. *Turborotalita humilis* (Brady)
   Locality TU 1144
   a. Spiral view, ×240
   b. Edge view, ×250
   c. Umbilical view, ×240
5. *Turborotalita humilis* (Brady)
   Locality TU 1144
   a. Spiral view, ×240
   b. Edge view, ×245
   c. Umbilical view, ×240

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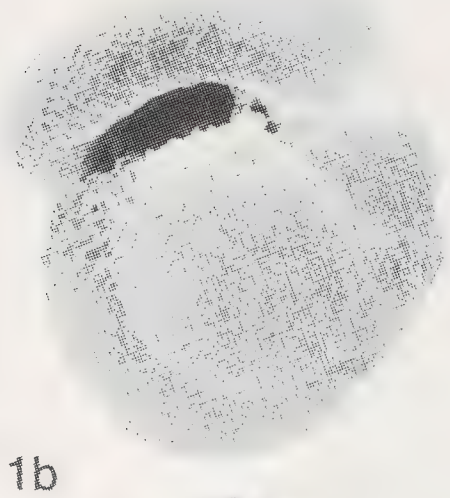
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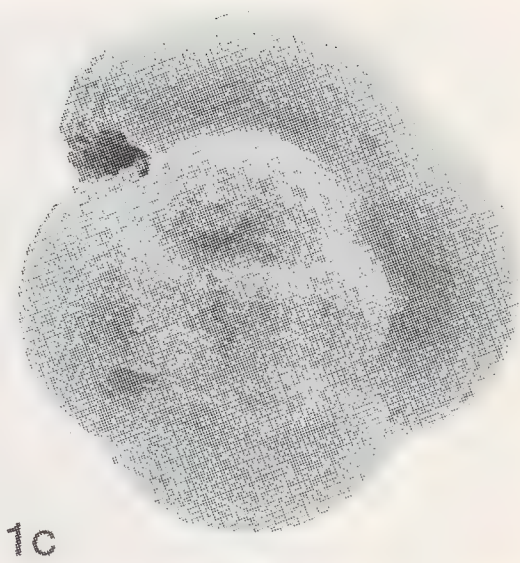
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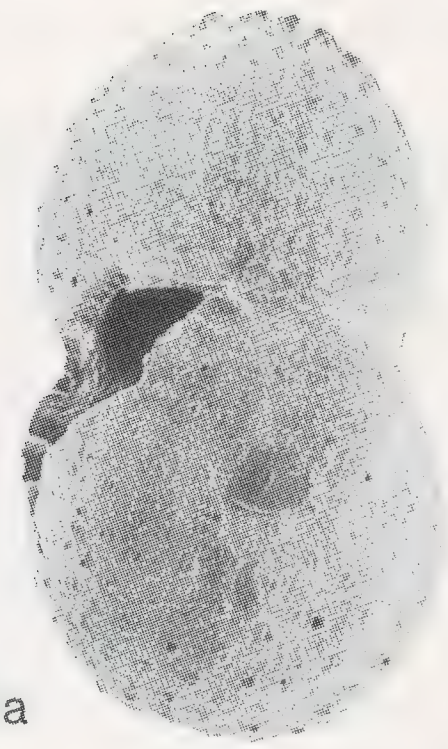
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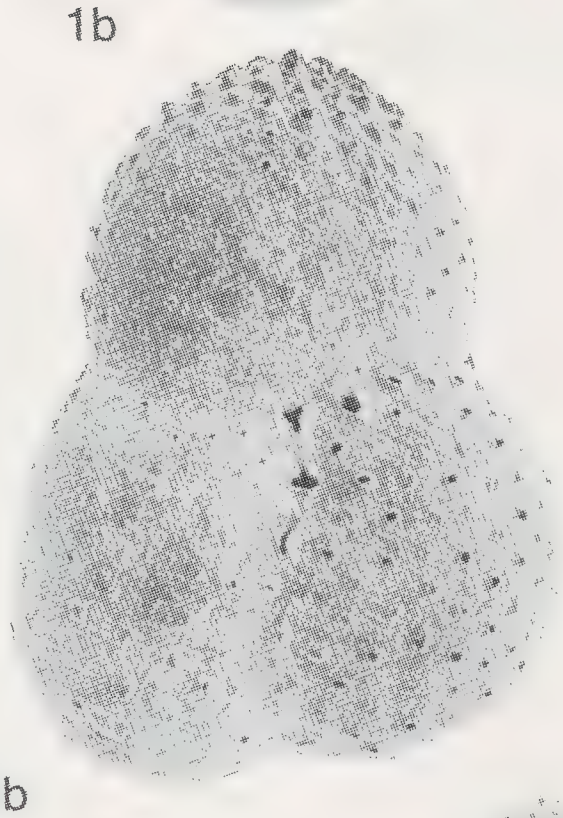
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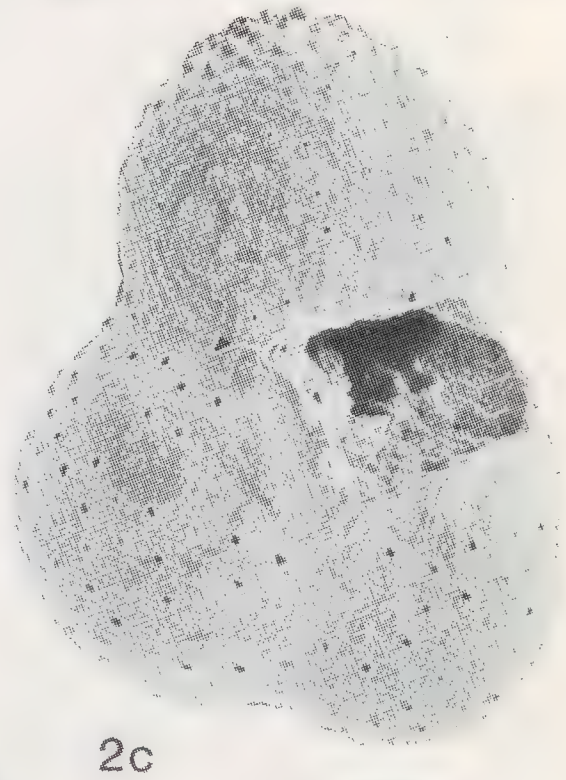
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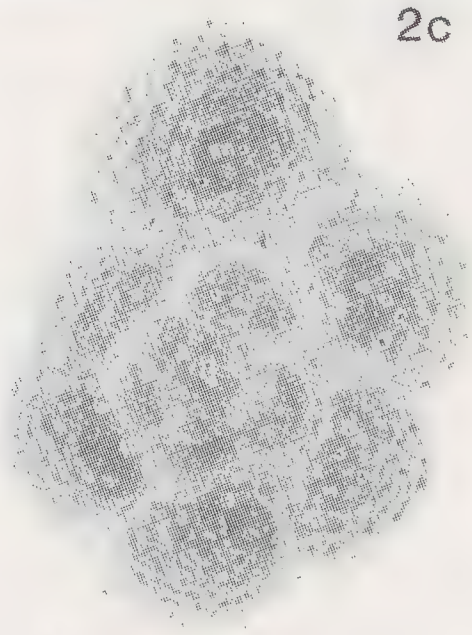
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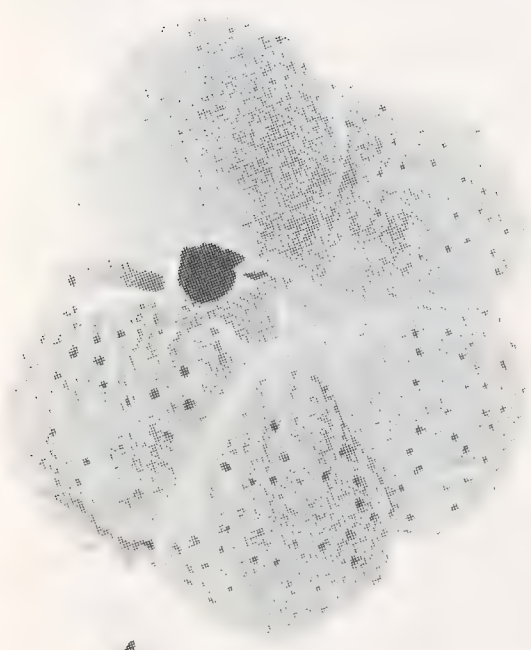
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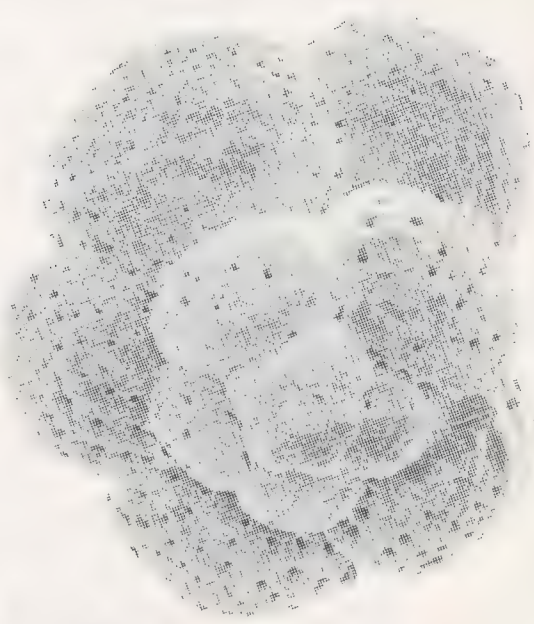
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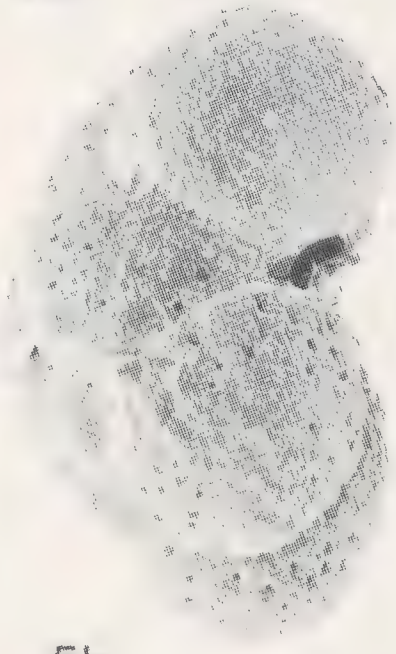
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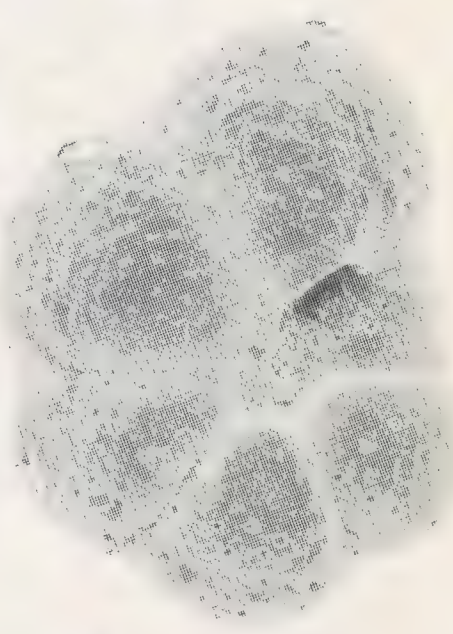

5c

PLATE 3

Blow (1969, p. 254) has referred the following land based sections to Zone N. 18 as follows: Donni Sandstone of Saipan, Janum Formation of Guam, Bowden Formation (median part) of Jamaica, and Trubi Marl (lowest part) of Sicily. He recognized N. 18 also on Vanua Levu Island (Fiji), in Papua, Java, Borneo, and Venezuela. The Lami Limestone of Viti Levu Island, Fiji, has been referred to Zone N. 18 (Adams, Rodda and Kiteley, 1979, p. 324, 327, 329). The zone is present in deep-sea cores from the Indo-Pacific and Atlantic (including Caribbean and Gulf of Mexico provinces).

B. LOCALITY TU 1324

Locality TU 1324 is on the road to Istal (Santa Rosa), which is the former railroad right-of-way, 5 km west of Mexico Highway 185, at a point 16 km north of the side road to Jesus Carranza, Veracruz, Mexico. The lithology at this exposure, as at TU 1144, is a hard, calcareous clay of uniform buff color. The residue on a No. 200 U.S. Standard Series Sieve is conspicuously the tests of foraminifera, both planktics and benthics, with abundant quartz grains that are smaller in diameter than most of the foraminifera. The material was collected by E. H. and H. E. Vokes and W. H. Akers, 1979.

The following planktic foraminifera were identified at TU 1324:

Biorbulina bilobata (d'Orbigny)
Candeina nitida nitida d'Orbigny
Globigerina bulloides bulloides d'Orbigny
G. decoraperta Takayanagi and Saito
G. cf. *G. incisa* (Bronnimann and Resig)
G. nepenthes Todd
G. cf. *G. nepenthes* Todd, juvenile(?)
Globigerinita glutinata (Egger)
G. uvula (Ehrenberg)
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. ruber (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa Bolli
G. venezuelana (Hedberg)
Globorotalia (Obandyella) margaritae Bolli and Bermudez
G. (O.) scitula (Brady)
G. (Menardella) cultrata limbata (Fornasini)
G. (M.) miocenica Palmer
Globorotaloides hexagona hexagona (Natland)
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Neogloboquadrina acostaensis (Blow)
N. humerosa (Takayanagi and Saito)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiie
Sphaeroidinellopsis seminulina seminulina (Schwager)
Turborotalita humilis (Brady)

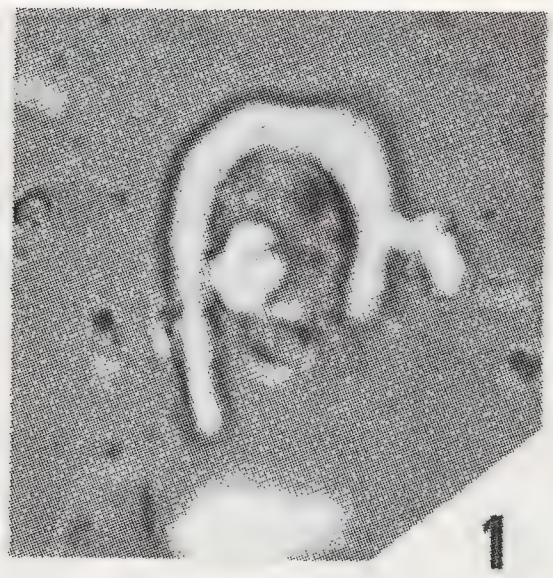
A rich calcareous nannoflora is present at TU 1324, and the following are only a few of the significant species that were identified:

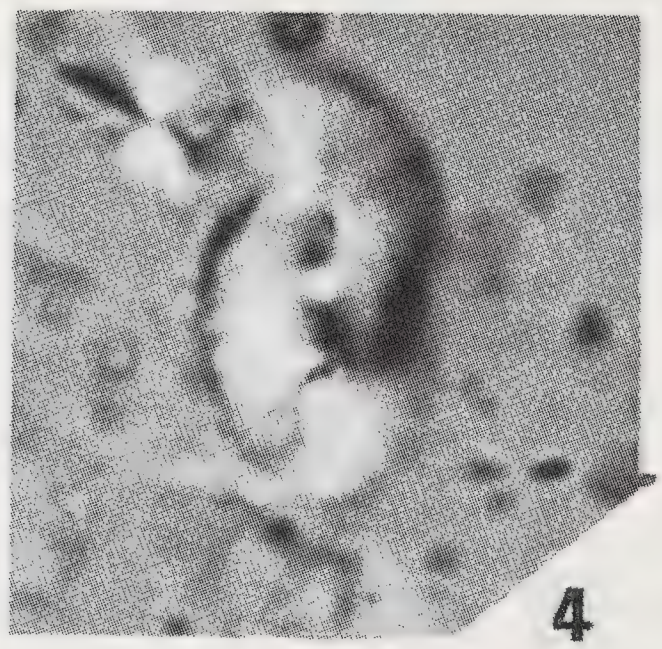
Ceratolithus rugosus Bukry and Bramlette
Discoaster brouweri Tan
D. pentaradiatus Tan
D. surculus Martini and Bramlette
Sphenolithus abies Deflandre

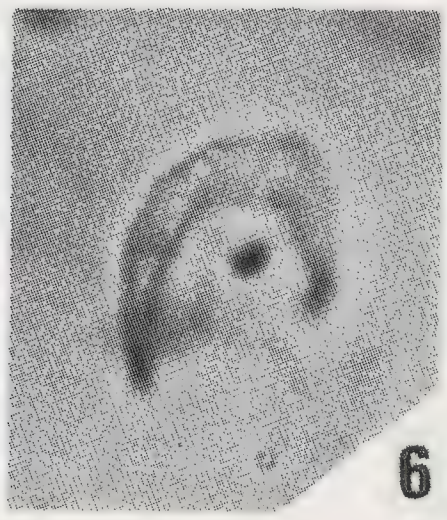
Geologic Age of Beds at TU 1324 and Correlations with Other Strata

Globigerina nepenthes is typically developed at TU 1324, and, although this development has been observed in older beds, it is characteristic of Zone N. 19 in association with the microassemblage listed above. *Ceratolithus rugosus* was recorded in low frequency. Calcification of other, more slender forms creates a close resemblance to *C. rugosus*. If the identification of the species here is correct, the occurrence with *Globigerina nepenthes* indicates Zone N. 19. If the *Ceratolithus* species is in actuality an older one that is highly calcified, the beds can still be referred no lower than Zone N. 18, because of the presence of *Globorotaloides hexagona hexagona* and *Globigerinoides conglobatus conglobatus*, forms that are not known to occur below Zone N. 18. The precise age of these beds notwithstanding, the microplankton are quite similar to the assemblage at TU 1144, and both assemblages are typical of the Lower Pliocene.

Blow (1969, p. 257) has referred Zone N. 19 to beds in Jamaica, Papua (New Guinea), Java, Sicily, Fiji (Vanua Levu Island), Guam, and Saipan. The Suva Marl Formation of Viti Levu Island, Fiji, is a highly fossiliferous sequence that only recently has been studied thoroughly and assigned to Zone N. 19 (Adams, Rodda and







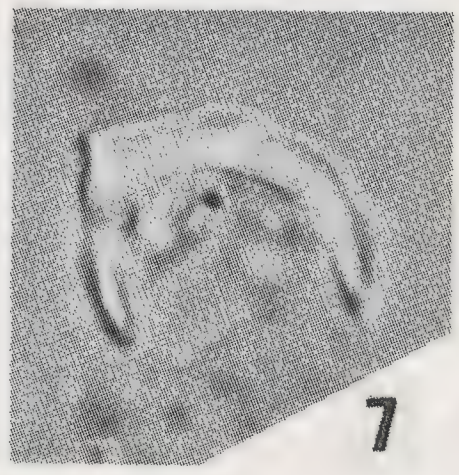


PLATE 4

Figures

1. *Amaurolithus delicatus* Gartner and Bukry, ×2100
   Locality TU 1332
2. *Amaurolithus delicatus* Gartner and Bukry, ×2626
   Locality TU 1332
3. *Ceratolithus rugosus* Bukry and Bramlette, ×2500
   Locality TU 1324
4. *Helicopontosphaera sellii* Bukry and Bramlette, ×3150
   Locality TU 1332
5. *Helicopontosphaera sellii* Bukry and Bramlette, ×2100
   Locality TU 1332

6, 7. *Amaurolithus primus* (Bukry and Percival) Gartner and Bukry, 1975, ×2100
   Locality TU 1333

Kiteley, 1979, p. 327). The zone has been recognized in many deep-sea cores from the Indo-Pacific and the Atlantic (including Gulf of Mexico and Caribbean provinces).

C. LOCALITY TU 1323

This locality is a roadcut at Istal (Santa Rosa), on the side road that was the old railroad right-of-way, 10 km west of Mexico Highway 185, at a point 16 km north of the side road to Jesus Carranza, Veracruz, Mexico. The lithology, like that at nearby TU 1324, is a hard, calcareous clay of uniform buff color. The residue on a No. 200 U.S. Standard Series Sieve is different in general appearance from that at TU 1324 in lacking quartz grains (conspicuous at TU 1324) and in having abundant fragments of mollusks. Beds here were collected by H. E. and E. H. Vokes and W. H. Akers.

The planktic foraminiferal assemblage includes the following:

Biorbulina bilobata (d'Orbigny)
Candeina nitida nitida d'Orbigny
Globigerina bulloides apertura Cushman
G. bulloides bulloides d'Orbigny
G. decoraperta Takayanagi and Saito
G. nepenthes Todd
Globigerinita glutinata (Egger)
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. quadrilobatus sacculifer (Brady)
G. ruber (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa Bolli
G. venezuelana (Hedberg)
Globorotalia (Obandyella) margaritae Bolli and Bermudez
G. (O.) scitula (Brady)
G. (Menardella) cultrata limbata (Fornasini)
Globorotaloides hexagona hexagona (Natland)
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Neogloboquadrina acostaensis (Blow)
Orbulina universa d'Orbigny
Prosphaeroidinella parkerae Ujiie
Sphaeroidinellopsis seminulina seminulina (Schwager)
S. subdehiscens subdehiscens (Blow)
Turborotalita humilis (Brady)

The nannoflora at TU 1323 is a typical Lower Pliocene assemblage resembling those from TU 1144 and TU 1324.

Geologic Age of Beds at TU 1323

The rich microfossil assemblages at TU 1323 are typical of the Lower Pliocene biota of bathyal middle and low latitude regions in both the Indo-Pacific and the Atlantic-Caribbean-Gulf of Mexico provinces. The age of the beds is Early Pliocene, somewhere between Zones N. 18 and N. 19. Further examination may reveal additional species of planktic foraminifera or calcareous nannofossils that will indicate a precise biostratigraphic position. More definitive index fossils have not yet been identified. The occurrence here of *Globigerinoides conglobatus conglobatus* and *Globorotaloides hexagona hexagona* indicates a position no lower than Zone N. 18, and the presence of *Globigerina nepenthes* indicates a position no higher than Zone N. 19.

D. LOCALITY TU 1332

This locality is behind the power substation on the west side of Mexico Highway 185, 8.2 km north of the junction (at Campo Nuevo) to Medias Aguas; 47.3 km north of Rio Jaltepec, Veracruz, Mexico. The lithology, like that at the other Lower Pliocene localities of this report, is a hard, calcareous clay of uniform buff color. The residue on a No. 200 U.S. Standard Series Sieve is predominantly tests of benthic and planktic foraminifera without quartz grains and mollusk fragments. Collected by E. H. and H. E. Vokes and W. H. Akers, 1979.

The following planktic foraminifera were identified at TU 1332.

Biorbulina bilobata (d'Orbigny)
Globigerina bulloides bulloides d'Orbigny
G. decoraperta Takayanagi and Saito
Globigerinita glutinata (Egger)
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. quadrilobatus sacculifer (Brady)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa Bolli
Globorotalia (Obandyella) margaritae Bolli and Bermudez

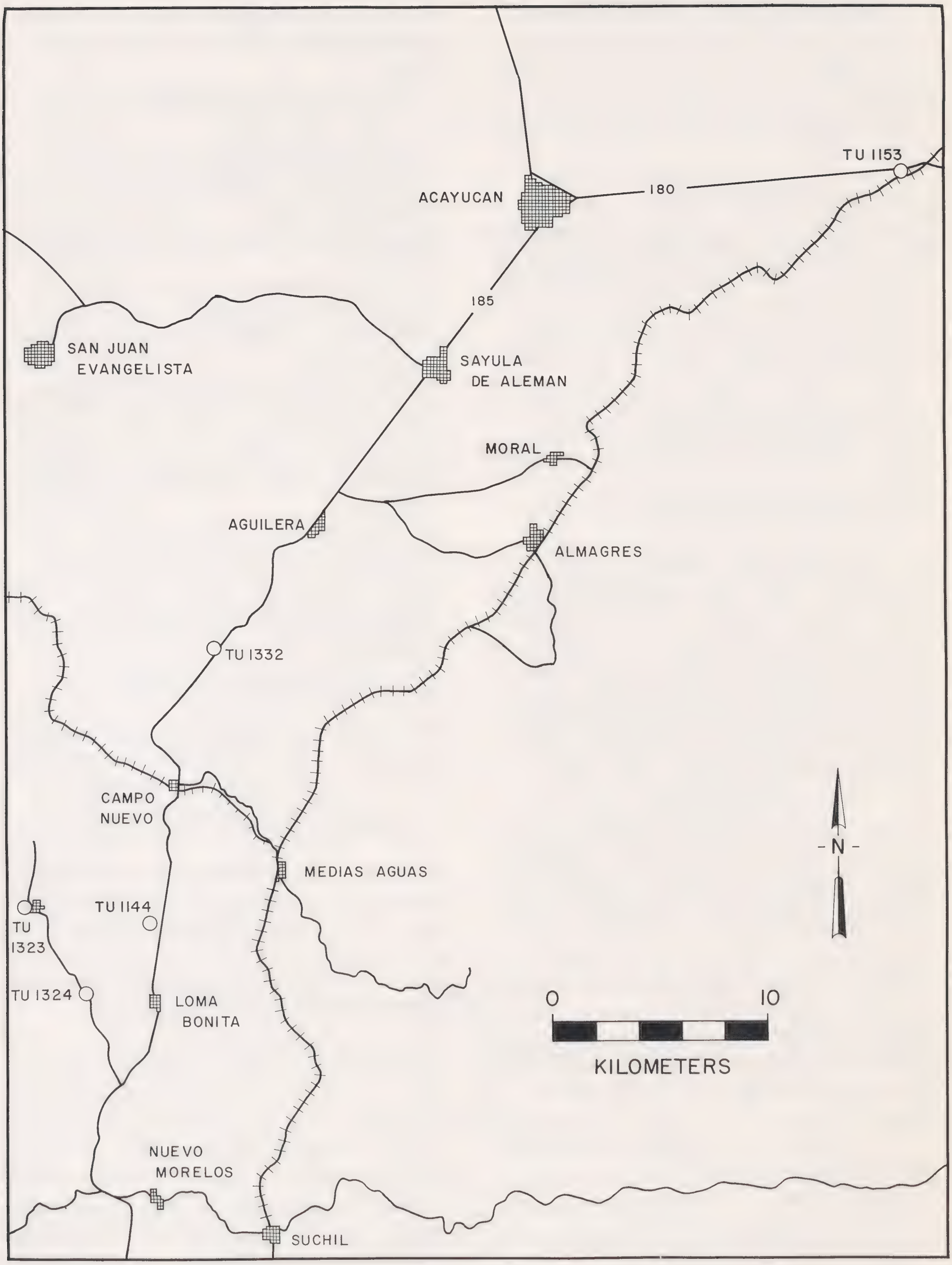


Figure 1. Lower Pliocene exposures discussed in this report, Isthmus of Tehuantepec, Mexico.

G. (Menardella) cultrata limbata (Fornasini)
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Neogloboquadrina acostaensis (Blow)
Orbulina universa d'Orbigny
Sphaeroidinellopsis seminulina seminulina (Schwager)
S. subdehiscens subdehiscens (Blow)
Turborotalita humilis (Brady)

The following calcareous nannofossils were identified at TU 1332, but they are only a few of the species that constitute a rich nannoflora at this locality:

Amaurolithus delicatus Gartner and Bukry
Discoaster brouweri Tan
D. pentaradiatus Tan
D. surculus Martini and Bramlette
D. variabilis Martini and Bramlette
Helicopontosphaera sellii Bukry and Bramlette
H. kamptneri Hay and Mohler
Sphenolithus abies Deflandre

Geologic Age of Beds at TU 1332

As at TU 1323, the stratigraphic position of the strata exposed at TU 1332 is somewhere between Zones N. 18 and N. 19, Lower Pliocene. The occurrence of *Globigerinoides conglobatus conglobatus* indicates a position not lower than Zone N. 18, and *Amaurolithus delicatus* suggests a position not higher than Zone N. 19.

E. LOCALITY TU 1153

This roadcut on Mexico Highway 180, at Km 16, east of Acayucan, Veracruz, Mexico, exposes a mottled, buff and light gray clay. Residue on a No. 200 U.S. Standard Series Sieve is largely tests of foraminifera and acicular limonite. The locality is on the Potrerillos Dome and has been mapped as Lower Miocene and referred to the Encanto Formation (Contreras Velazquez *et al.*, 1956, map). Samples were collected by H. E. and E. H. Vokes, 1974.

The following planktic foraminifera were identified at TU 1153:

Biorbulina bilobata (d'Orbigny)
Candeina nitida nitida d'Orbigny
Globigerina bulloides apertura Cushman
G. bulloides bulloides d'Orbigny
G. decoraperta Takayanagi and Saito
G cf. *G. incisa* (Bronnimann and Resig)
G. nepenthes Todd
G. nepenthes Todd, juvenile(?)
Globigerinerlla calida (Parker)
G. uvula (Ehrenberg)
Globigerinoides conglobatus conglobatus (Brady)
Globigerinita glutinata (Egger)
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. quadrilobatus sacculifer (Brady)
G. ruber (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa Bolli
G. venezuelana (Hedberg)
Globorotalia (Obandyella) margaritae Bolli and Bermudez
G. (Menardella) cultrata limbata (Fornasini)
G. (Truncorotalia) crassaformis (Galloway and Wissler)
Globorotaloides hexagona hexagona (Natland)
Hastigerina (H.) siphonifera siphonifera (d'Orbigny)
Neogloboquadrina acostaensis (Blow)
N. humerosa (Takayanagi and Saito)
Orbulina universa d'Orbigny
Pulleniatina primalis Banner and Blow
Sphaeroidinellopsis seminulina seminulina (Schwager)
S. subdehiscens subdehiscens (Blow)
Turborotalita humilis (Brady)

The beds at TU 1153 are rich in calcareous nannofossils, containing the species listed for other Lower Pliocene sites.

Geologic Age of Beds at TU 1153

The coincidence of *Globigerina nepenthes* with *Globorotaloides hexagona hexagona* and *Globigerinella calida* indicates a stratigraphic position in Zone N. 19 or the upper part of Zone N. 18. The nannoflora and the planktic foraminifera are typical of the Lower Pliocene.

F. LOCALITY TU 1333

Fresh excavations in railroad cuts behind a newly constructed grain elevator, just north of the road junction at Campo El Chapo, Veracruz, Mexico, were sampled by H. E. and E. H. Vokes with the writer during the summer of 1980. Soft clay yielded rich foraminiferal and calcareous nannofossil assemblages of probable bathyal origin. *Melonis affinis* (Reuss), *Uvigerina hispida* Schwager, and *Amphimorphina stainforthi* (Cushman and Renz) are prominent benthics. The following planktic foraminifera occur at this site:

Biorbulina bilobata (d'Orbigny)
Globigerina decoraperta Takayanagi and Saito
G. nepenthes Todd
Globigerinoides conglobatus conglobatus (Brady)
G. obliquus extremus Bolli and Bermudez
G. obliquus obliquus Bolli
G. quadrilobatus quadrilobatus (d'Orbigny)
G. ruber (d'Orbigny)
Globoquadrina altispira altispira (Cushman and Jarvis)
G. altispira globosa (Bolli)
G. venezuelana (Hedberg)
Globorotalia (Obandyella) margaritae Bolli and Bermudez
G. (Menardella) cultrata limbata (Fornasini)
Neogloboquadrina acostaensis (Blow)
N. humerosa (Takayanagi and Saito)
Orbulina universa d'Orbigny
Sphaeroidinellopsis seminulina seminulina (Schwager)
S. subdehiscens subdehiscens (Blow)

The following calcareous nannoplankton were identified at TU 1333:

Amaurolithus delicatus Gartner and Bukry
A. primus (Bukry and Percival) Gartner and Bukry
A. tricorniculatus (Gartner) Gartner and Bukry
Ceratolithus acutus Gartner and Bukry
Discoaster brouweri Tan
D. pentaradiatus Tan
D. surculus Martini and Bramlette
Helicopontosphaera sellii Bukry and Bramlette
Reticulofenestra pseudoumbilica (Gartner) Gartner
Sphenolithus abies Deflandre

Geologic Age of Beds at TU 1333

Concurrence of *Globigerinoides conglobatus conglobatus* and *Amaurolithus delicatus* indicates a stratigraphic position in Zone N. 18 or N. 19, Lower Pliocene.

V. TAXONOMY

See Part 1 (Akers, 1979, p. 9-16), for taxonomy of additional forms listed from the Lower Pliocene localities but not included below.

A. PLANKTIC FORAMINIFERA

Globigerina incisa (Bronnimann and Resig). Pl. 1, fig. 1a-c
Globorotalia (Turborotalia) incisa BRONNIMANN and RESIG, 1971, Initial Reports of the Deep Sea Drilling Project, vol. 7, Washington (U.S. Government Printing Office), p. 1278-1279, pl. 45, fig. 5, 7; pl. 46, fig. 1-8.
Globigerina fossulata POAG, *in* POAG and SWEET, 1972, Contr. Geol. Geophys. Oceanogr. Gulf of Mexico, vol. 3, p. 257, fig. 8-12e.

Remarks: The species may have become extinct in the Caribbean-Gulf of Mexico region later than it disappeared from the Pacific, as Bronnimann and Resig (1971, p. 1278-1279) do not record it above Zone N. 20 in deep-sea cores from the southwestern Pacific. Many specimens from the Lower Pliocene of Mexico do not have sutures so deeply incised as seen in specimens from the northern Gulf Coast and elsewhere.

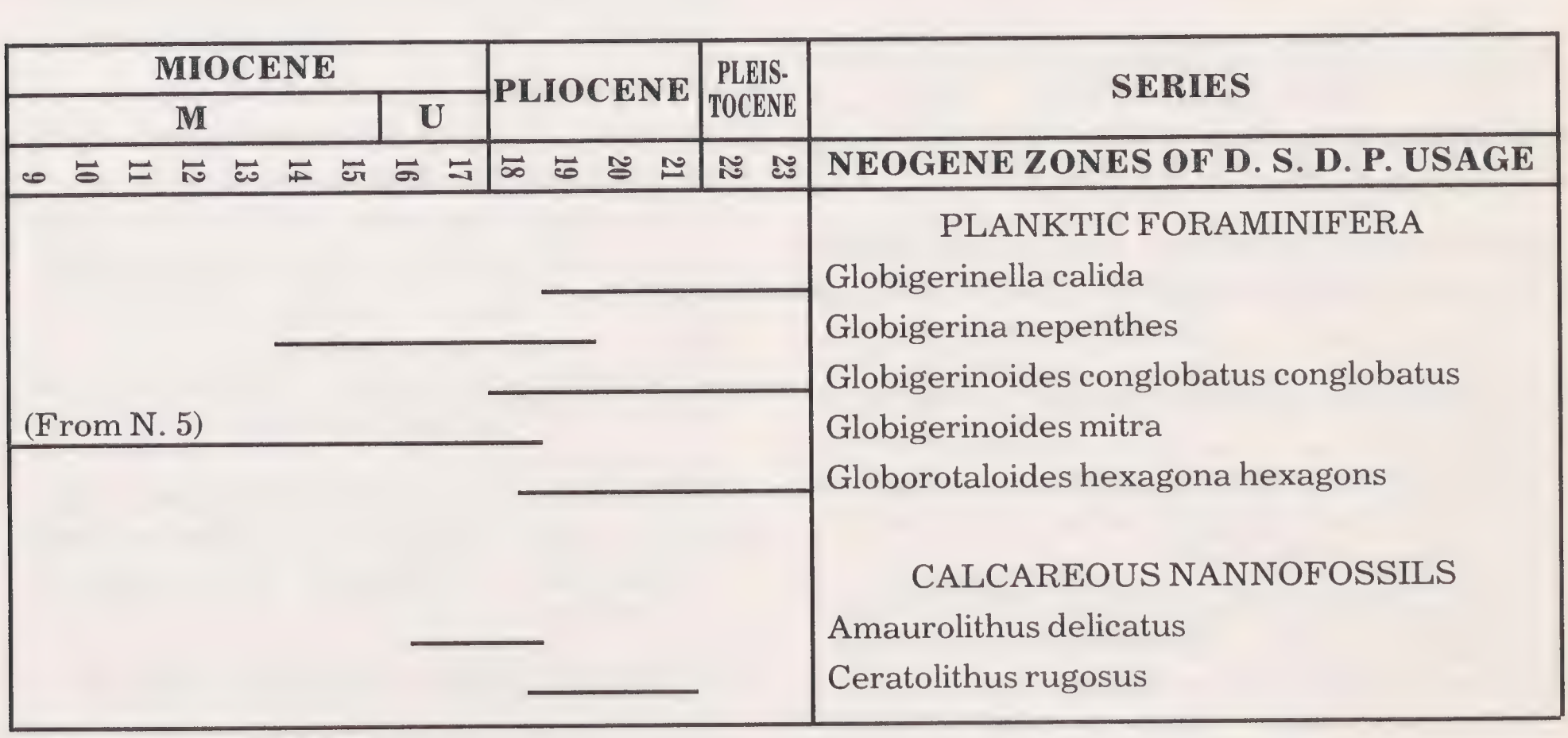


Figure 2. Index Microfossils for the Lower Pliocene (Zones N. 18 and N. 19) of Mexico.

Specimens illustrated from TU 1153 show secondary calcification in the sutures. They are assigned tentatively here.

Globigerina nepenthes Todd. Pl. 1, fig. 2a-c

Globigerina nepenthes TODD, 1957, U.S. Geol. Survey, Prof. Paper 280-H, p. 301, pl.78, fig. 7a-b.

Sphaeroidinellopsis nepenthes (Todd) var. *constricta* BERMUDEZ, 1961, Mem. III Congr. Geol. Venezolano, vol. 3, Bol. Geol. Publ. Esp. 3, (1960), p. 1278, pl. 10, fig. 2a-b.

Remarks: Forms listed and illustrated as G. cf. G. *nepenthes* Todd, juvenile(?) have been found by the writer in fine sieve fractions (pl. 1, fig. 3a-b). The maximum diameter of most specimens is 200 microns. The writer has found these forms in beds that yield typical adults of G. *nepenthes* including TU 1324 and TU 1153 of Mexico, the Bowden Formation of Jamaica (Blow's "Holotype" beds for his Zones N. 18 and N. 19), the Suva Marl Formation of Fiji (Zone N. 19), and the Lower Pliocene of several continental slope core holes in the northern Gulf of Mexico.

Globigerinella calida (Parker). Pl. 1, fig. 4a-c

Globigerina calida PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 221, pl. 1, fig. 9-13, 15.

Globigerina calida praecalida BLOW, 1969, Proc. First International conference on Planktonic Microfossils, vol. 1, p. 380-381, pl. 13, fig. 6, 7; pl. 14, fig. 3. AKERS, 1979, Tulane Stud. Geol. Paleont., vol. 15, no. 1, p. 10, pl 2, fig. 7.

Globigerinella calida (Parker), KENNETT and SRINIVASAN, 1983, Neogene Planktonic Foraminifera, Hutchinson Ross Publ. Co., p. 240, pl. 60, fig. 7-9.

Remarks: Kennett and Srinivasan (1983, p. 240) consider this form to range from N. 19 to the Holocene.

Globigerinita glutinata (Egger). Pl. 1, fig. 5a-c

Globigerina glutinata EGGER, 1893, Abh. K. Bayer. Akad. Wiss. München, CL II, vol. 18, p. 371, pl. 13, fig. 19-21.

Tinophodella ambitacrena LOEBLICH and TAPPAN, 1957, Washington Acad. Sci., Jour., vol. 47, no. 4, p. 114, fig. 2, 3.

Globigerinoides parkerae BERMUDEZ, 1961, Bol. Geologia, Pub. Esp. no. 3; Mem. Terc. Congr. Geol. Venezolano, tom. 3, p. 1.232, pl. 10, fig. 10, 11.

Globigerinita glutinata (Egger), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 246, pl. 9, fig. 1-16.

Globigerinoides conglobatus conglobatus (Brady). Pl. 1, fig. 6a-c

Globigerina conglobata BRADY, 1879, Quart. Jour. Micr. Science (new ser.), vol. 19, p. 286.

Globigerinoides conglobatus conglobatus (Brady), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 229, pl. 3, fig. 1-5.

Globigerinoides mitra Todd. Pl. 2, fig. 1a-c

Globigerinoides mitra TODD, 1957, U.S. Geol. Survey, Prof. Paper 280-H, p. 302, pl. 78, fig. 3, 6.

Remarks: Saito *et al.* (1976) placed G. *mitra* in a new genus, *Globicuniculus*, but Kennett and Srinivasan (1983, p. 76) retained the species in *Globigerinoides*.

Globorotalia (Truncorotalia) crassaformis (Galloway and Wissler). Pl. 2, fig. 2a-c

Globigerina crassaformis GALLOWAY and WISSLER, 1927, Jour. Paleontology, vol. 1, p. 41, pl. 7, fig. 12.

Globorotalia crassaformis (Galloway and Wissler), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 235, pl. 4, fig. 17, 18, 20, 21.

Remarks: Specimens from the Pliocene of Mexico are rare and small and are referred here, *sensu lato*.

Globorotalia (Menardella) miocenica Palmer. Pl. 2, fig. 3a-c

Globorotalia menardii (d'Orbigny) *miocenica* PALMER, 1945, Bull. Amer. Paleontology, vol. 29, no. 115, p. 70, pl. 1, fig. 10

Globorotaloides hexagona hexagona (Natland). Pl. 2, fig. 4a-c, 5a-c

Globigerina hexagona NATLAND, 1938, Univ. Calif., Scripps Inst. Oceanography, Bull. Tech. Ser., vol. 4, no. 5, p. 149, pl. 7, fig. 1.

Globoquadrina hexagona (Natland), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 244, pl. 8, fig. 5-13.

Globorotaloides hexagona hexagona (Natland), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 373-374.

Pulleniatina primalis Banner and Blow. Pl. 3, fig. 1a-c

Pulleniatina primalis BANNER and BLOW, 1967, Micropaleontology, vol. 13, no. 1, p. 142, pl. 1, fig. 3-8; pl. 3, fig. 2.

Sphaeroidinellopsis seminulina seminulina (Schwager). Pl. 3, fig. 2a-c, 3a-b
Globigerina seminulina SCHWAGER, 1866, *Novara* Exped., 1857-1859, Geol. Theil., vol. 2, pt. 2, p. 256, pl. 7, fig. 112. BANNER and BLOW, 1960, Contr. Cushman Found. Foram. Res., vol. 11, p. 24, pl. 7, fig. 2 (neotype).
Sphaeroidinellopsis seminulina seminulina (Schwager), BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 337, pl. 30, fig. 7.

Turborotalita humilis (Brady). Pl. 3, fig. 4a-c, 5a-c
Truncatulina humilis BRADY, 1884, Rept. Voy. *Challenger*, Zoology, vol. 9, p. 665, pl. 94, fig. 7.
Globigerina cristata HERON-ALLEN and EARLAND, 1929, Jour. Roy. Micr. Soc., ser. 3, vol. 49, pt. 4, art. 27, p. 331, pl. 4, fig. 33-39.
Globigerinita parkerae LOEBLICH and TAPPAN, 1957, Washington Acad. Sci., Jour., vol. 47, no. 4, p. 113, fig. 1.
Globigerinita humilis (Brady), PARKER, 1962, Micropaleontology, vol. 8, no. 2, p. 249, pl. 10, fig. 1-25.
Turborotalita humilis (Brady), PARKER, 1967, Bull. Amer. Paleontology, vol. 52, no. 235, pl. 146-147, pl. 17, fig. 10. BLOW, 1969, Proc. First International Conference on Planktonic Microfossils, vol. 1, p. 373, pl. 51, fig. 4 *(Turborotalia [sic]* cf. *humilis* (Brady)). SEIGLIE AND CUCURULLO, 1971, Carib. Jour. Sci., vol. 11, no. 3-4, p. 110, pl. 4, fig. 64a, b, 66a-67b.
Globorotalia sp. cf. *Turborotalita humilis* (Brady), SEIGLIE and CUCURULLO, 1971, Carib. Jour. Sci., vol. 11, no. 3-4, p. 110, pl. 4, fig. 61a-63b, 65a, b.

Remarks: The writer agrees with Seiglie and Cucurullo (1971, p. 110) that forms having a less complex bulla and fewer infralaminal apertures are probably ancestral to those forms cited as typical of the species. These authors may also be correct in referring the less complex form to *Globanomalina pumilio* Parker, 1962.

B. CALCAREOUS NANNOFOSSILS

Amaurolithus delicatus Gartner and Bukry, Pl. 4, Fig. 1, 2
Amaurolithus delicatus GARTNER and BUKRY, 1975, Jour. Research, U.S. Geol. Survey, vol. 3, no. 4, p. 456-457, fig. 7a-f.

Amaurolithus primus (Bukry and Percival) Gartner and Bukry, Pl. 4, fig. 6, 7
Ceratolithus primus Bukry and Percival, 1971, Tulane Stud. Geol. Paleont., vol. 8, p. 126, pl. 1, fig. 12-14.
Amaurolithus primus (Bukry and Percival) Gartner and Bukry, 1975, Jour. Research, U.S. Geol. Survey, vol. 8, no. 4, p. 457, fig. 7g-l.

Helicopontosphaera sellii Bukry and Bramlette. Pl. 4, fig. 4, 5
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NOTES ON THE GENUS *AGNOCARDIA* (MOLLUSCA: CARDIIDAE) WITH THE DESCRIPTION OF A NEW SPECIES FROM THE PLIOCENE OF FLORIDA

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I. ABSTRACT

Nine species, including one from the Lower Eocene of France and eight, ranging in age from Claibornian (Middle Eocene) to basal Pleistocene, from the western Atlantic fossil faunas are here referred to the genus *Agnocardia* Stewart, 1930; also included is one new species from the Middle Pliocene of Florida. Two species, one from the Oligocene of Germany and one from the Middle Eocene of California, mentioned by Stewart in his discussion, are here considered as not being members of the taxonomic group.

II. INTRODUCTION

Agnocardia, originally described as a subgenus of *Trachycardium* Mörch, 1853, by Stewart (1930, p. 264) with *Cardium (Trachycardium) claibornense* Aldrich (1911, p. 3, pl. 1, fig. 4) as type species, has been considered a subgenus of *Acanthocardia* Gray, 1851, by Keen (1969, p. 585; 1980, p. 16) and as a separate genus by the writer (1977, p. 153) and by Dockery (1982, p. 69). Although the hinge of the Middle Eocene type species is unknown, that of the Lower Oligocene (Vicksburgian) *Cardium glebosum* Conrad (1848, p. 292) has been well illustrated by Dockery (1982, text figs. 39, 40-1 and pl. 32, figs. 2a, 3a). It is similar to that of *Cardium aculeatum* Linnaeus, 1758, type species of *Acanthocardia,* in being relatively long with the cardinal and lateral teeth on a straight line relative to each other; however, the surface ornamentation of the two genera is strikingly different. That of *Agnocardia* consists of 40 or more flat-topped radial costae, separated by square-sided interspaces of half or less the width of the ribs, that bear on their upper surface spines of an inverted "V" shape. Commonly on the medial part of the valve ribs, with rather short and low, closely approximate spines, alternate with those bearing more distantly spaced, high, prominent ones (see pl. 2). In contrast, *Acanthocardia aculeata* is ornamented by approximately one-half as many radial ribs, which are wider, with broadly rounded upper surfaces and proportionately wider, less sharply delimited interspaces; the ribs bearing roundly nodose, spike-like spines that tend, on the median and posterior parts of the valve, to rise from the mid-point of the rib-width and anteriorly to become heavy, transverse nodes. The inverted "V" spines of *Agnocardia* are somewhat like those of *Cardium isocardia* Linnaeus, type species of *Trachycardium,* but are laterally symmetrical without the strong ventral prolongation of the posterior side that is characteristic of the latter genus. Furthermore the hinge of *Trachycardium* is relatively shorter and arched, with the laterals more ventral in position than the cardinal teeth.

SPECIES HERE REFERRED TO *AGNOCARDIA*

The following species appear to be referable to *Agnocardia:*

1. *Cardium convexum* Deshayes (1858, p. 559, pl. 55, figs. 18-21); Lower Eocene (Cuisian), Aizy, Paris Basin. This appears to be the earliest species yet known, and in-so-far as the writer is aware, the only European species referable to this genus. The writer has seen no specimens, but examination of the illustrations given by Cossmann and Pissaro (1906, pl. 18, sp. 69-18) reveals the alteration of spine size on adjacent costae and a hinge of typical form. The figures are stated to be twice natural size, suggesting a specimen with a length of approximately 7 mm; Cossmann

(1886, p. 157) previously had cited a specimen also from Aizy that is 12.5 mm in diameter, stating that the species is always very rare.

2. *Cardium (Trachycardium) claibornense* Aldrich (1911, p. 3, pl. 1, fig. 4); Claibornian Eocene (? = Archusa Marl Member of Cook Mountain Formation) at De Soto, Clarke County, Mississippi. The Aldrich illustration was reproduced by Harris (1919, pl. 41, fig. 8), together with a detail of the surface ornamentation (his fig. 8a) of a fragment from the Gosport Sand at Claiborne, Alabama. An additional specimen (his fig. 9) from Colliers Ferry, Burleson County, Texas, said by Harris (*ibid.*, p. 132) to have "very much the general appearance of *claibornense*," does not represent this species, according to Palmer and Brann (1965, p. 27).

Aldrich's description states that the shell is large, "covered with numerous ribs which are square in section and ornamented with close-set triangular imbrications . . . The sunken spaces between the ribs are not half their width . . . height 35, breadth 33 mm." A study of the original illustration, which appears to be about two-thirds natural size, suggests that there are at least 47 costae.

Upper Eocene forms tentatively referred to this species, as "cf. *claibornense*," have been reported from the Santee Limestone of South Carolina (Harbison, 1944, p. 6, pl. 1, figs. 6, 8), and from the Inglis Formation and the Avon Park Limestone, Levy County, Florida (Richards *in* Richards and Palmer, 1953, p. 52, pl. 11, figs. 5, 6). It should be noted, however, that two incomplete external molds of specimens from the Inglis, collected from spoil dumps made during the construction of the Florida Cross-State Barge Canal near Inglis, Florida (TU localities 778, 812) show an alternation of spine size on adjacent radials that is much more pronounced than that shown by Harris on the small surface area in his figure 8a (see pl. 2, fig. 4). The Upper Eocene Florida specimens may well represent a different species but are too incomplete to permit any certain conclusions.

3. *Cardium glebosum* Conrad (1848, p. 122), spelled (in faunal lists) as "*C. (Trachycardium) globosum* C." by Conrad (1865, p. 7) (not *C. globosum* Bean, 1839, Jurassic, England). *Agnocardia glebosum* was described from the "Eocene" (=Lower Oligocene) near Vicksburg, Mississippi, where it was said to be "rare and obtained only in fragments." For a full synonymy with illustration of the incomplete holotype specimen, plus more complete specimens from the Red Bluff, Mint Springs, and Byram formations of the Vicksburg Group, and excellent drawings of the hinge and interior of the valves, the reader is referred to Dockery's monograph of the Vicksburg Bivalvia (1982, pp. 69-70, pl. 32, figs. 1-5, text. figs. 39, 40-1). Exception must be taken, however, to his statement that *A. glebosum* differs from the Chipolan (Lower Miocene) *A. acrocome* (Dall) "in having A-shaped spines of equal strength on its radial costae rather than alternating rows of strong and weak spines." Although it appears that the spines on the more ventral portion of the ribs on adult

PLATE 1

Figures

1-3. *Agnocardia spinosifrons* H. E. Vokes, n. sp.
   1. Paratype USNM 377406 (× 1); Length 42.5 mm, height 48.5 mm.
   2. Paratype USNM 377407 (× 3); Length 14.8 mm, height 14.5 mm.
   3. Holotype USNM 377405; Length 31.3 mm, height 33.7 mm.
      3a. (× 1.5); 3b (× 6) enlarged detail of surface ornament to show differing size of spines on alternate ribs.

   All specimens from locality TU 1177; Pinecrest Formation (Pliocene), Collier County, Florida.

4. *Agnocardia acrocome* (Dall)
   USNM 234512 (× 1.5); Length 35.5, height 37.5 mm.
   Locality TU 830; Chipola Formation (Lower Miocene), Tenmile Creek, Calhoun County, Florida.

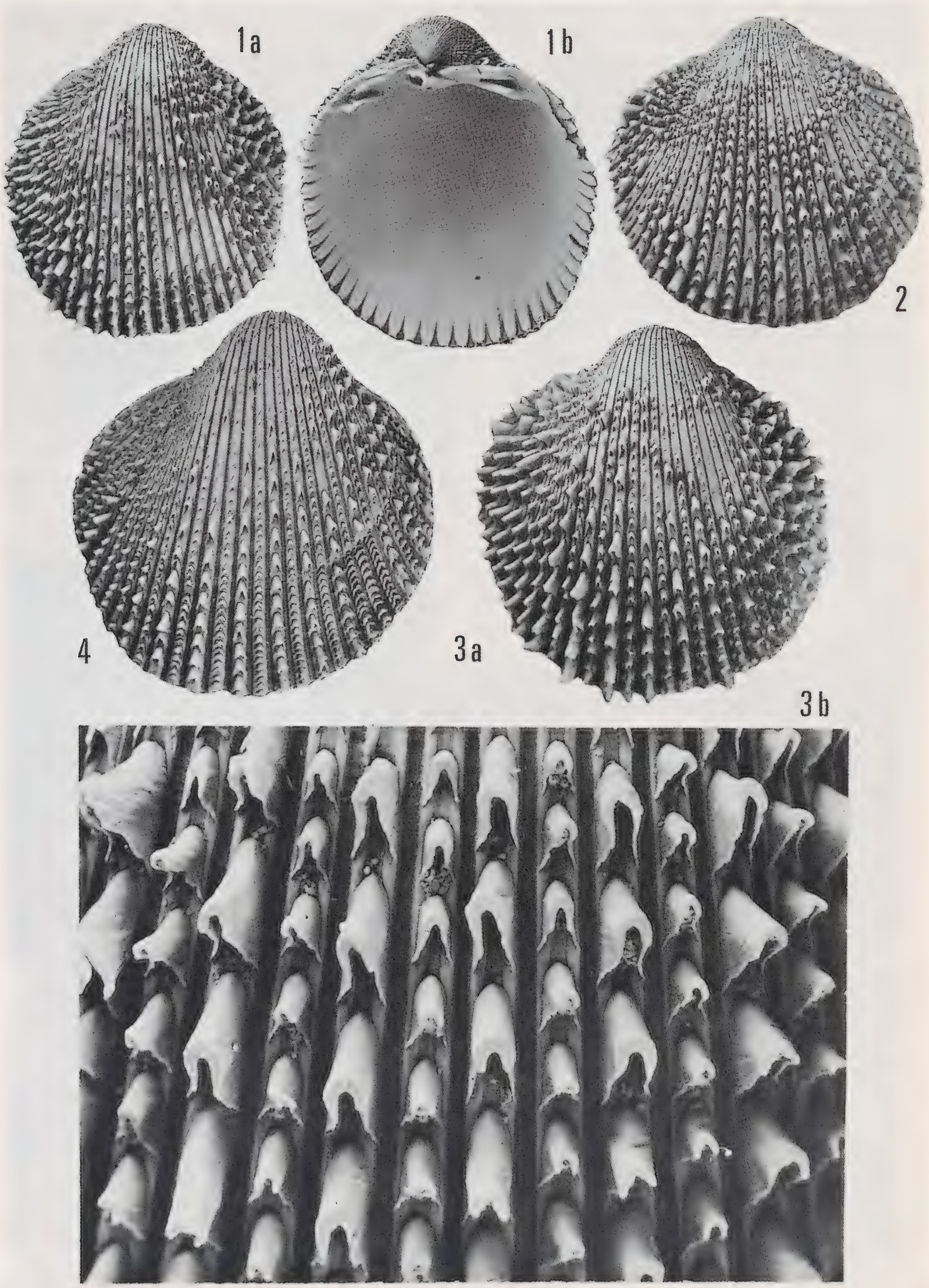


PLATE 1

specimens are more or less of equal strength, examination of the more immature area (see especially Dockery's pl. 32, fig. 4) shows that the alternation of spine size occurs also in this species. An immature valve in the Tulane University collections from the Red Bluff Formation at TU 642 has 42 radial ribs.

Dall (1916, p. 498) included *"Cardium (Trachycardium)" glebosum* Conrad in the fauna of the Upper Oligocene beds at Flint River, Georgia, and (p. 488) also listed it as present in the "Ocala." Since the Ocala Limestone is of Upper Eocene age and to be correlated with the Inglis Formation and the Avon Park Limestone, cited above, it may be that Dall's Ocala form is the same as that cited by Richards (1953) as "cf. *claibornense.*"

Harris (1951, pl. 41, figs. 11, 12) subsequently illustrated two "imprints of exteriors" of a cardiid collected from the Ocala Limestone at the Dixie Lime Products quarry at Reddick, Florida, that certainly represents a species of *Agnocardia;* unfortunately he does not indicate the degree of magnification, if any. If the figures are of natural size they do not agree with the characteristic ornamentation on areas of equivalent rib size on either *A. claibornense* or *A. glebosum.* It is also to be noted that the internal molds of *"Cardium* sp. (with pointed beaks)" (*ibid.*, pl. 41, figs. 7, 8) from the same locality at Reddick to which Harris refers the imprints as "probably" of the same species, are of a narrower and proportionately much higher form than either of the above species.

4. *Cardium acrocome* Dall (1900, p. 1081; 1903, pl. 48, fig. 2); Chipola Formation, Lower Miocene (Burdigalian), Calhoun County, Florida. Dall's original illustration and description of the immature type specimen were reprinted by Gardner as *Cardium (Acanthocardia) acrocome* (1926, p. 133, pl. 22, fig. 7). She also stated that "the type [which came from the banks of the Chipola River "1 mile below Baileys Ferry"] is unique." Subsequent Tulane University collections contain 36 valves from exposures along Tenmile Creek, west of the Baileys Ferry area, the majority being from the basal strata of the formation; however, only two valves have been recovered from exposures along the Chipola River. Similar disproportionate differences in the relative distribution of other cardiid species have been observed (see Vokes, 1977, p. 148, table 2); the most unusual being the more than 13,300 valves of *Trigoniocardia simrothi* (Dall) (1900, p. 1104; 1903, pl. 48, fig. 8) collected from exposures along the Chipola River, with but two valves being found in the Tenmile Creek section. The sediments at the localities from which these collections were made are so similar in composition and grain size as to give no hint of the ecological factors responsible for the distributional differences.

The variation in spine size on the adja-

PLATE 2

Figures

1-3. *Agnocardia acrocome* (Dall)

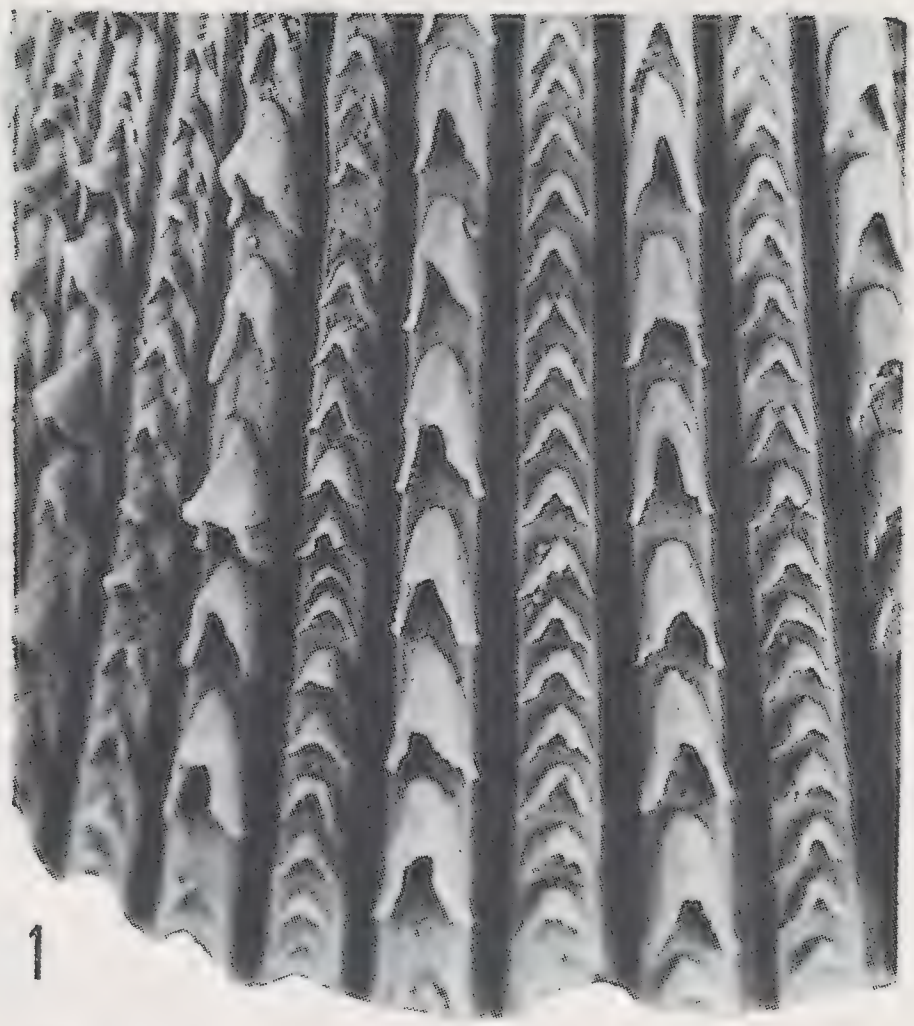
1. USNM 234512 (× 4); detail of surface ornament of specimen shown on plate 1, figure 4. Locality TU 830.
2. USNM 377400 (×6); lateral view to show differing height of spines on alternate ribs. Locality TU 830.
3. USNM 377401 (× 6); view of surface of unusual specimen having two ribs with small spines between two large-spined ones on median surface. Locality TU 951.

All specimens from Chipola Formation (Lower Miocene), Tenmile Creek, Calhoun County, Florida.

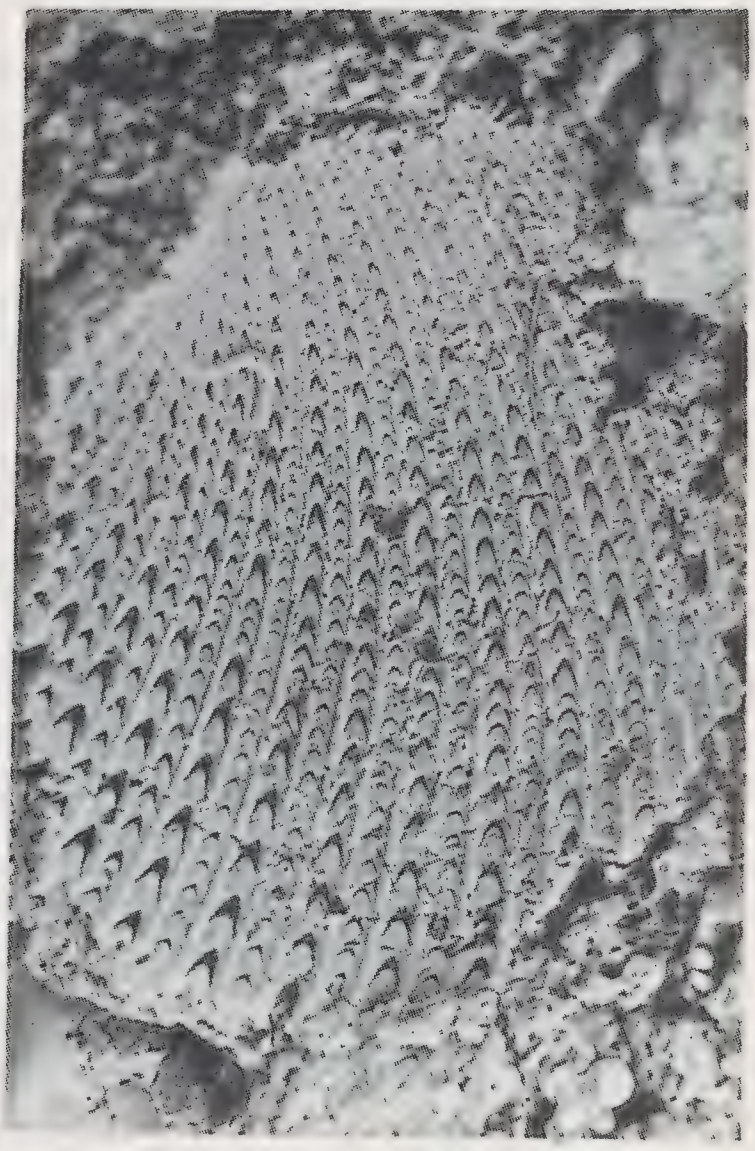
4. *Agnocardia* new species ?

USNM 377399 (× 3); view of mold of exterior of valve surface showing strong variation in spine size on fragmentary valve.

Locality TU 778, Inglis Limestone (Upper Eocene), Florida Barge Canal, south of Inglis, Florida.



1



4

2

3

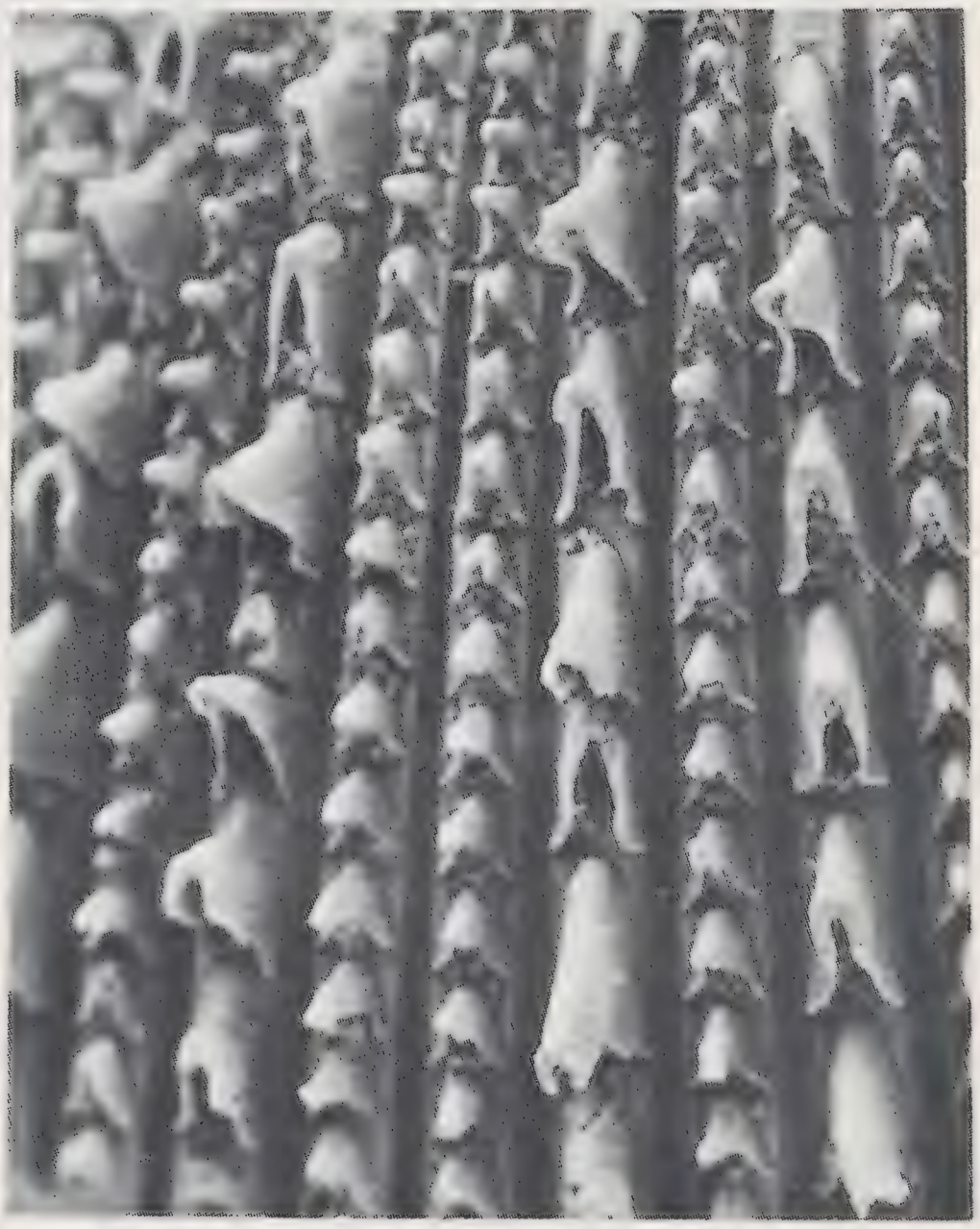


PLATE 2

cent ribs is more strikingly developed in *A. acrocome* than in the other species referable to this genus, the differences being expressed both in the relative strength of the spines and in their total heights (see pl. 2, figs. 1-3). Anteriorly the alternation of spine sizes tends to remain, but on some specimens the finer ones may increase in size until they approach that of the heavier ones. Posteriorly, however, an interesting variation occurs: the weak postero-ventral angulation is marked by the presence of a strong-spined rib; followed posteriorly by a low-spined one, then another strong-spined one with four low-spined ones intervening before the next strong-spined one. Posterior to this there are three or four low-spined ribs followed by two or three strong-spined ones near the posterior dorsal margin. The number of costae varies from 45 to 47, the majority having 46. The largest specimen, from TU locality 951 on Tenmile Creek, has a height of 55.6 mm and a length of 46.7 mm; Dall's immature type had a height and length of 7.5 mm.

5 (?) *Cardium (Trachycardium) pessoae* Maury (1925, pp. 306 [Portuguese], 307 [English]; pl. 17, figs. 15, 18); Pirabas Formation, Lower Miocene, Rio Pirabas, Pará, Brazil. The shape of the internal mold, 35 mm long and 40 mm high, with a long, straight hinge, is very similar to that characteristic of *Acrocome*. Maury's figure of the external mold of the anterior portion of the shell clearly shows the presence of inverted "V"-shaped spines on the ribs, but it is not certain whether there is an alternation in spine size nor, in fact, if the spines are laterally symmetrical or have a degree of prolongation on their posterior flank. Maury's description of the spines as being "Λ-shaped, or lambda-shaped" in no way solves the problem. The number of ribs is said to be "about fifty."

This is the only South American species of which the writer is aware that might be referable to *Agnocardia*.

6. *Cardium (Trachycardium) cinderellae* Maury (1917, p. 375, pl. 62, fig. 4); "Zone B" Gurabo Formation, Lower Pliocene, near Los Quemados, Dominican Republic. Known only from the Dominican Republic where it is relatively rare, *A. cinderellae* has essentially the same number of costaeas *A. acrocome,* varying between 44 (holotype, *fide* Maury) and 49, with the average on the specimens presently available for study being 47. The costae tend to have a shallow, median groove that is coincident in position with the dorsal end of the spines; the narrow slightly raised margins of the grooves bear the lateral terminations of the spines that, however, flare out from their base and extend over the margins of the inter-rib areas. Posteriorly there tend to be three or four smaller-spined ribs between the more strongly ornamented ones, while the ribs reaching the anterior margin of the valve have spines of approximately equal strength on each one. The spines of *A. acrocome* are distinctly less flared out laterally and seldom overhang any of the inter-rib areas; furthermore, they are relatively narrower and more "pinched in" near their upper ends, thus having a more distinctly spinose appearance.

7. *Cardium (Trachycardium) cinderellae* Maury, variety *alternatus* Hubbard (1920, p. 115, pl. 19, figs. 2, 3, 4); Lares Formation, (?) Upper Oligocene, Porto Rico. Described as having a "sculpture like *C. cinderellae* Maury but the shell is larger, shorter, and more convex. It may possibly deserve a specific name, but the specimens are too fragmental to warrant this." Combined with the differences in valve shape and proportion is the statement that the surface has only "about thirty-six broad flat ribs" in contrast to the average of 47 ribs in *A. cinderellae*. This, plus the difference in geologic age of the two forms, makes it probable that *Agnocardia alternata* (Hubbard) is a valid species.

8. *Agnocardia spinosifrons* n. sp. Pinecrest Formation, Lower Pliocene, Florida (see description, below).

9. *Cardium (Acanthocardia?) dissidepictum* Woodring (1925, p. 135, pl. 18, figs. 10, 11); basal Pleistocene, Bowden, Jamaica. The type is a relatively small specimen (length 23 mm, height 23.4 mm) but Woodring also cites a "restored broken valve" of "approximately 35 mm length and 37 mm height." A topotype fragment in the Tulane collections, 37 mm in length, has ribs that show a rib-top width of 2.6

mm, while a broken valve that has a height of 32.5 mm, has rib-tops that are but 1.2 mm wide at their ventral extremity; the relative proportions of these rib-tops would suggest that the fragment came from a valve that was at least 70 mm in height. Woodring cites the type as having 43 radial ribs; the broken valve mentioned above has 46. The spines tend to be laterally compressed toward their midheight, but their ventral ends, and to some extent their lower sides, flare out over the narrow, channeled interspace margins in a manner similar to that observed on *A. cinderellae.*

As suggested by Stewart (1930, p. 265), *A. dissidepictum* appears to be the last surviving member of the genus.

SPECIES INCORRECTLY REFERRED TO *AGNOCARDIA*

In his original discussion of *Agnocardia,* Stewart (1930, p. 265) referred two species to it that, in the opinion of the present writer, are not members of this genus:

1. *Cardium sorrentoensis* M. A. Hanna (1927, p. 285, pl. 41, figs. 10, 12, 14); La Jolla Formation, Middle Eocene, San Diego County, California, and also cited as present in the Simi Valley area (*ibid.,* p. 260). The ornamentation of the ribs, as described by Hanna and shown in his figure 14, consists of costae with "chevron-shaped spines" alternating with others that have only "smaller node-like spines," which appear to be rounded and of an *Acanthocardia*-like form, although much smaller in size. This alternation is well depicted by Keen (1980, pl. 3 fig. 9a), who also shows that the intercostal areas, described by Hanna as being "about as wide as the ribs," are marked by a radial ornament that seems to represent narrow grooves.

The presence of alternation of rib-top ornament is indeed suggestive of *Agnocardia,* but the nature of the nodose finer spines plus the relatively wider intercostal areas with a radial ornamentation, are distinctive and together with its early Middle Eocene age – essentially about the same as that of the first appearance of the genus – implies a different ancestry.

2. *Cardium rectispina* von Koenen (1893, p. 1148, pl. 76, fig. 5a-d). Stewart (1930, p. 265) also suggested that *Agnocardia* "may be represented in the . . . Oligocene of Germany – Lattorfien – by *'C.' rectispina* von Koenen." Examination of von Koenen's figure 5d shows that the costae on this small form – the type has a width of 7.7 mm and a height of 8.1 mm – bear spines of the same size on adjacent ribs, with the intercostal areas, which are slightly narrower than the ribs, bearing rather well-developed transverse threads or laminae. There is also some suggestion that the posterior wing of the chevron-shaped spines is slightly longer than the anterior and is somewhat like that of species of *Trachycardium* s.s., but the shape of the hinge is more that of *Acanthocardia.*

III. SYSTEMATIC DESCRIPTION

Family CARDIIDAE Lamarck, 1809
Subfamily CARDIINAE Lamarck, 1809
Genus AGNOCARDIA Stewart

Agnocardia STEWART, 1930, Acad. Nat. Sci. Phila., Spec. Publ. 3, pp. 37, 294.

Type species: *Cardium (Trachycardium) claibornese* Aldrich, 1911, by original designation.

AGNOCARDIA SPINOSIFRONS H. E. Vokes, new species
Plate 1, figures 1-3

Diagnosis: Shell moderately large, sub-circular in outline, in adult stage slightly higher than long, with a relatively low, roundly inflated umbo; anterior and ventral margins broadly and regularly rounded, posterior only slightly convex; surface ornament of 43 or 44 radial costae each bearing numerous inverted "V"-shaped spines, those on the ribs of the anterior and median portions of the valve surface tending to vary in strength and number on alternate costae but becoming more equal in strength toward the ventral margin of the larger specimen, there being four larger spines contrasted with six smaller ones per centimeter on the mid-height of the valve and four vs. five on the same ribs at the ventral margin; with four or five costae with fine spines immediately posterior to the last strong-spined rib, then three small-spined ones, succeeded by three stronger-spined ones; individual spines tending to be "pinched in" at mid-

height and when complete showing a prolonged elongation at their ventral terminus, lateral margins slightly flared below but not extending over the inter-rib areas; costae on the anterior and the anterior part of the median area with grooves that are aligned with the dorsally pointed ends of the spines; inter-rib areas about one-half to one-third the width of the adjoining costae, narrower anteriorly than on median or posterior areas, and smooth or with narrow growth rugae; interior margins denticulate; hinge typical of the genus.

Holotype: USNM 377405; length 31.1 mm, height 33.7 mm, diameter (right valve) 14.2 mm. Locality TU 1177.

Paratype: USNM 377406; length 42.5 mm, height 48.5 mm, diameter (right valve) 20.6 mm. Locality TU 1177.

Paratype: USNM 377407; length 14.8 mm, height 14.5 mm, diameter (left valve) 7.3 mm. Locality TU 1177.

Type locality: TU 1177, Pinecrest Formation, Mule Pen Quarry, north side of Florida highway 846, 9.1 miles east of U. S. highway 41 at Naples Park (SE¼Sec. 24, T48S, E26E), Collier Co., Florida.

Discussion: The median-sized specimen, which has been selected as holotype of this species because of the better preservation of the spinose rib ornament, compares in general size with the Tulane specimen of *A. dissidepictum* (Woodring) from Bowden, Jamaica, but differs in shape, having a straighter, more dorsoventrally trending posterior margin, and in the nature of the spinous ornament, the spines being smaller and more numerous on the Jamaica specimen, with seven and nine spines per centimeter as compared with four or five on the same relative area of the present species. Furthermore, the basal portion of the ribs, while slightly flaring, do not project over the intercostal areas as they do in both *A. dissidepictum* and the Dominican *A. cinderellae*.

The specific name *spinosifrons* is derived from the Latin terms, *spinosus*-"spiny or thorny" and *frons*-"foliage."

IV. LOCALITY DATA

The following are Tulane University fossil localities:

778. Inglis Formation, Upper Eocene. Florida Cross-State Barge Canal at U. S. highway 19, just south of Inglis, Levy County, Florida.
812. Inglis Formation, Upper Eocene, Florida Cross-State Barge Canal, south side, ca. 1.5 miles west of U. S. highway 19, at Inglis, Levy County, Florida.
830. Chipola Formation, Lower Miocene. Tenmile Creek, at power line crossing about one mile west of the Chipola River (SE¼ Sec. 12, T1N, R10W), Calhoun County, Florida.
951. Chipola Formation, Lower Miocene. Tenmile Creek, about 1¼ miles west of Chipola River (SE¼ Sec. 12, T1N, R10W), Calhoun County, Florida.
1177. Pinecrest Formation, Middle Pliocene. Mule Pen Quarry, north side of Florida highway 846, 9.1 miles east of U. S. highway 41 at Naples Park (SE¼ Sec. 24, T48S, R26E), Collier County, Florida.

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REVIEW

FOUNDATIONS OF STRUCTURAL GEOLOGY, by R. G. Park. Published by Blackie & Son Limited, Glasgow and London, 1982, viii + 135 pp., illus., paper $17.95 (distributed in the USA by Chapman and Hall, New York)

This book provides a brief introduction to Structural Geology and is intended to stimulate reader interest in this subject and to encourage him to pursue more advanced textbooks and scientific papers in this field. Thus, it includes a short and simple explanation of many of the concepts, principles, and terms used in modern structural studies. It is both clear and coherent as well as brief and efficient in its language and treatment. It should serve as a handbook useful to the student as a study guide or outline of the subject. It is generally up-to-date and well written. The index and the lists of references for further reading at the end of each section are most useful. It is recommended for those who need a condensed outline treatment of structural geology.

--H.C.S.

REVIEW

THE GREAT CHAIN OF HISTORY: William Buckland and the English School of Geology, by Nicolaas A. Rupke. Published by the Clarendon Press, Oxford, 1983, xii + 322 pp., 14 figs., $45.00

This volume presents a provocative and intriguing view of nineteenth century geology in England. The author chooses William Buckland as the leader of the "English School of Geology" which he presents as actively opposing and competing with the "Scottish School of Geology." Admitting that no English School of Geology has previously been defined, the author states that "the notion of British Geology does not allow for a historiography which is fine-grained enough to do justice to Buckland and his circle." He follows this statement with a lengthy and frequently tedious attempt to justify and document his thesis. Rupke's reasoning is seriously weakened by his unreserved attacks on the popularity of the writings of Charles Lyell and James Hutton and their influence on contemporary geology. In comparing these with the writings of his "English School" his arguments range from illogical to absurd. In a specific comparison of the popularity of Lyell's *Principles of Geology* with that of Buckland's *Bridgewater Treatise* he suggests that to the "considerable numbers of copies [of the Bridgewater Treatise] must be added all the books written by other members of the English school; for example, the *Outlines* by Conybeare and Phillips (1822); de la Beche's *Geological Manual* (1831) and his *Researches in Theoretical Geology* (1834); Phillips's *Guide to Geology* (1834) and his *Treatise on Geology* (1837); even Bakewell's *Introduction to Geology* (1828) and Mantell's *Wonders of Geology* (1838)." Further he states "It did not go through as many editions as Lyell's *Principles,* but a comparison of the number of editions is valueless unless the print-run and the price of each book are identical."

Historians must remain aware of the spectre of preconceived bias; a skilled historian admits his bias and attempts to minimize its effect in his writings. The iconoclastic approach to history is not recommended as a convincing method of argument. Unfortunately, this book seems to suffer from such disadvantages. The following quoted paragraph may show this:

> "The modern perspective of earth history owes little to Scottish geology. Huttonian uniformitarianism was fundamentally uncongenial to historical geology. Its vision of a permanent present made James Hutton object to invertebrate extinction. It also caused Charles Lyell to reject the evidence for the progressive succession of fossils. The common notion that modern geology originated with uniformitarianism is a hindrance to the unencumbered study of the origin of the new geology. The distinctive nature of English geology was in fact accentuated by the conscious manner in which it set itself apart from the Scottish tradition."

Strong words these; they are self-explanatory.

There is merit in this volume. There is useful and clear exposition of the work of William Buckland, especially as it related to the bone caves and the diluvial phenomena. Further, the point of view of the author is presented and should be considered by historians of geology. We may gain new insight into the contributions of some of the "English geologists." Provocative views have their place and should not be suppressed.

—H.C.S.

A NEW SPECIES OF *TURBINELLA* (MOLLUSCA:GASTROPODA) FROM THE PLIOCENE OF MEXICO, WITH A REVISION OF THE GEOLOGIC HISTORY OF THE LINE

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I. INTRODUCTION

In the 20 years since the writer reviewed the genus *Turbinella* in the New World (Vokes, 1964; 1966) there have been many changes in the age assignments of the formations in which the various species occur. Thus, in the table of distribution for the lineage of what was termed therein (1964, p. 40) the "*angulata*" group (in reference to *Turbinella angulata*,* the Recent Caribbean species), those forms shown as "middle Miocene" are now known to be mid-Pliocene (*T. scopula* Olsson, from the Rio Banano Formation of Costa Rica, and *T. magdalenensis* Weisbord, from the Tubará Group of Colombia) or basal Pleistocene (*T. textilis* Guppy, from the Bowden Formation of Jamaica). In the Florida section what was in 1964 an "unnamed upper Miocene formation" is now the Pinecrest unit, of middle Pliocene age. The Caloosahatchee Formation is assumed to be late Pliocene, as it overlies the Pinecrest and underlies the early Pleistocene Bermont Formation (the "unnamed post-Caloosahatchee formation" of 1964).

With this new information it would appear that there are no members of the "*angulata*" lineage known between the lower Miocene Chipolan species (*T. chipolana* Dall and *T. dalli* Vokes) and the middle Pliocene ones. This is, in large measure, due to the fact that there are almost no geologic outcrops of this age available. For some unknown reason (late Miocene glaciation has been suggested, or perhaps a subsidence of activity along the mid-Atlantic Ridge), there are virtually no beds of late Miocene-early Pliocene age in tropical America.

One of the few exceptions to this is in the Cibao Valley of the Dominican Republic. Here we have a beautiful section ranging from extremely shallow water (Cercado Formation) to very deep water (Gurabo Formation). The lithologies range from conglomerates through sands to shales and coralline limestones. Somewhere in this array of environmental conditions one would assume that the representative of the "*angulata*" line would have lived. But the only examples of *Turbinella* present are either members of the "ancestral" lineage (a new species near *T. valida* Sowerby) or *T. praelaevigata* Vokes (= *T. praeovoidea* Maury *non* Vredenberg), a member of the smooth "*laevigata*" line.

Everywhere in the pre-Pleistocene fossil record of the Caribbean a representative of the "*laevigata*" line seems to predominate. In the early Miocene Cantaure Formation of Venezuela (TU 1269) specimens of *T. falconensis* (Hodson) litter the ground. In younger (Pliocene) beds of the same area (Panamá to Trinidad) we see other members of the line (*T. trinitatis, riosecana,* and *colinensis*). In the Florida Pinecrest beds *T. regina* Heilprin is almost ubiquitous.

Today, however, the sole member of the line, *T. laevigata* Anton, is confined to an area along the coast of Brazil, from Amapá to Espirito Santo (Rios, 1975, p. 108), or approximately from the Equator to the Tropic of Capricorn. Here it is found on sandy bottoms, in shallow water. This is the same ecologic niche now pre-empted by *T. angulata* in the Northern Hemisphere. Where this knobby interloper was hiding through the middle and upper Miocene still must remain a mystery. Perhaps, in time, additional localities will fill in the missing section but, for now, the mid-Pliocene sea comes in with a roar that makes the Noachian flood seem believable and brings with it a virtual "explosion" of the "*angulata*" line. In the southern Caribbean *T. angulata* appears (in the

*Complete references for all species mentioned will be found at the end of this paper.

guise of *T. magdalenensis)* in Colombia, and *T. scopula* is seen in Costa Rica. In addition, there is a new species, here described, in the Agueguexquite Formation of the Isthmus of Tehuantepec, Mexico, which is much nearer in shape to the almost smooth *T. scolymoides* of southern Florida than to the very knobby southern forms.

In Florida *T. scolymoides* is still confined to the late Pliocene Caloosahatchee and younger beds – no example has yet been discovered in the earlier Pinecrest beds. As was suggested in the 1966 paper, the absence of *T. scolymoides* from the Pinecrest is probably due to slightly cooler water during the Pinecrest deposition for, as Olsson noted in his original discussion of the Pinecrest fauna (*in* Olsson and Petit, 1964, p. 157), there is a large admixture of northern forms and the whole fauna has a "decidedly Chesapeake Miocene [*i.e.*, mid-Pliocene Yorktown Formation] aspect." This writer suggested that the change from the cooler water Pinecrest fauna to the more tropical Caloosahatchee fauna was brought about by the closing of the Isthmus of Panamá, with its resultant creation of the Gulf Stream bringing warmer waters across Florida (Vokes, 1966, p. 68).

Presumably *T. regina* was able to last for a period of time but was gradually eliminated by the more aggressive(?) "*angulata*" forms and, thus, diasppeared from the Northern Hemisphere by the end of the Pliocene, with the Pleistocene completely dominated by "*angulata*" species: *T. scolymoides, hoerlei,* and *angulata,* in Florida; *T. textilis* in Jamaica; and an undescribed species, presumably a descendant of *T. scopula,* in the Moín Formation of Costa Rica. (See Table 1 – a revised distribution chart for the "*angulata*" lineage.)

The origin of the entire *T. angulata* complex seems to lie with *T. dalli* Vokes from the lower Miocene Chipola Formation. All share virtually identical juvenile shells having an extremely large (ca. 5 mm in diameter) protoconch and strong nodes on all of the teleoconch whorls. The Chipolan contemporary of *T. dalli, T. chipolana* Dall, also has a large protoconch but loses the strong teleoconch nodes after a few whorls. The only other form with this type of development is the early Pleistocene *T. textilis* (Guppy), which when adult resembles the weakly shouldered *T. scolymoides*. However, *T. scolymoides* has strong nodes until approximately the sixth teleoconch whorl, at which point it begins to smooth out; *T. textilis* is just the opposite, the intermediate whorls are almost smooth until about the sixth whorl when it redevelops weak shoulder nodes (an adult of *T. textilis* has been figured by Pilsbry, 1922, pl. 25, fig. 5, as *T. textilis jamaicensis*).

In the 1966 study it was suggestsed that the Brazilian species *T. tuberculata* (Ferreira) was closely related to *T. angulata*

PLATE 1

Figures

1-3. *Turbinella hermani* E. H. Vokes, n. sp.
   1. (× 1) USNM 375457 (holotype); height 113 mm, diameter 44.2 mm.
   2. (× 2) USNM 375458 (paratype A); height 17.3 mm, diameter 8.8 mm.
   3. (× 1) USNM 375459 (paratype B); height 72 mm, diameter 30.9 mm.
   Locality of all: TU 638, Agueguexquite Formation, Mexico.

4. *Turbinella angulata* (Solander *in* Lightfoot).
   (× 2) USNM 838039; height 16.4 mm, diameter 10 mm (shell removed from an egg-capsule, showing "adult" sculpture on "embryonic" shell).
   Locality: TU R-75, Sisal, Yucatán, Mexico.

5. *Turbinella hoerlei* Vokes
   (× 2) USNM 375460; height 23.3 mm, diameter 11.7 mm.
   Locality: TU 201, Bermont Formation, Florida.

6. *Turbinella scolymoides* Dall
   (× 2) PRI 26917a; height 32 mm, diameter 15 mm.
   Locality: TU 519, Caloosahatchee Formation, Florida.

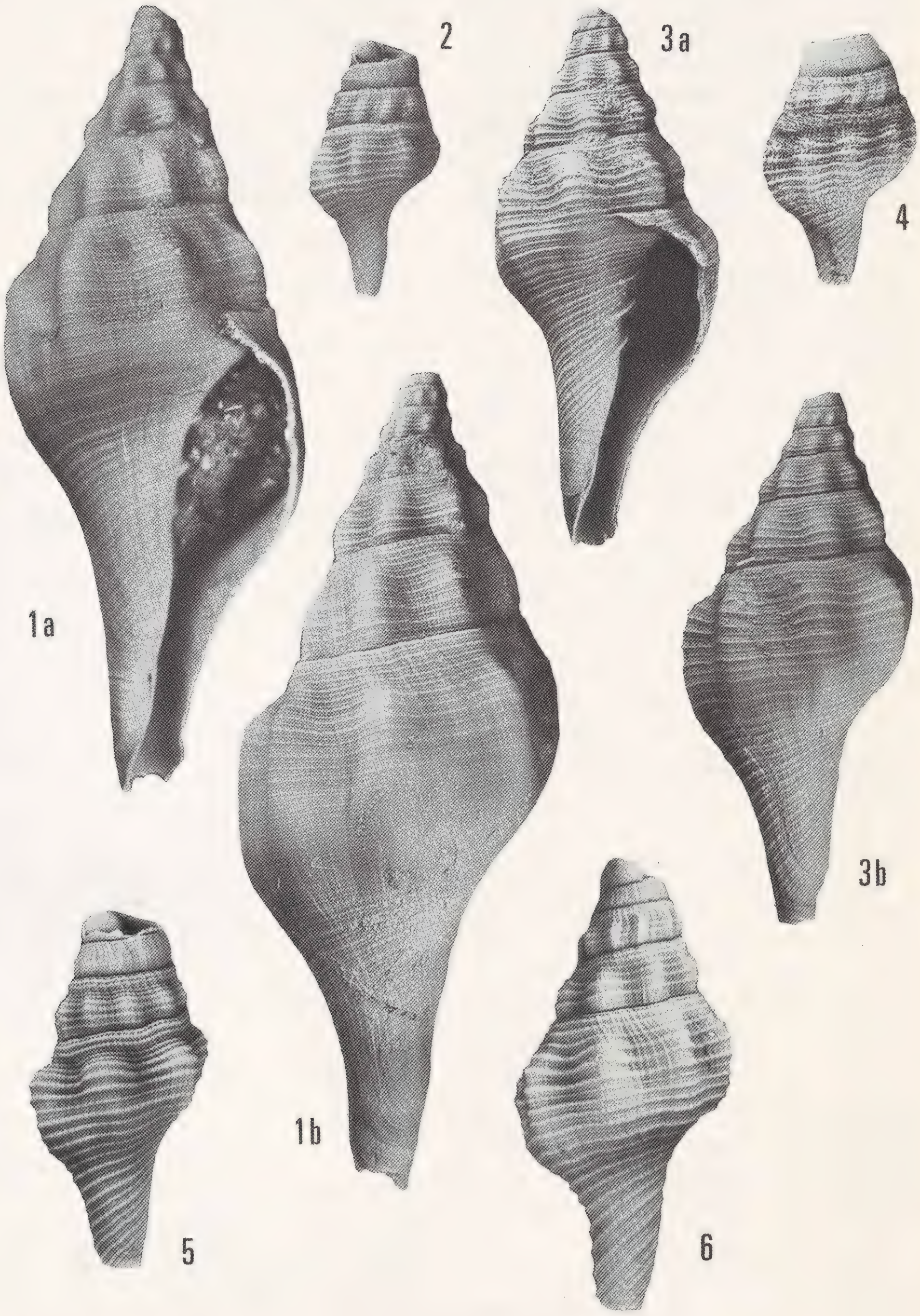

PLATE 1

and might be ancestral to it. However, since that time Ferriera has supplied the writer with plaster casts of *T. tuberculata* and it can be seen that the Brazilian species is more closely allied with the Dominican *T. valida,* and presumably is another member of the "ancestral" lineage, those species with a relatively small protoconch and extremely nodose shells. On the basis of comparative material sent by Ferriera, it is more likely that *T. tuberculata* is the adult of *T. grata* (Maury).

In addition to the changes seen in the history of the "*angulata*" lineage discussed herein, there are, not unexpectedly, many comparable changes in the other two groups previously discussed – the "ancest-

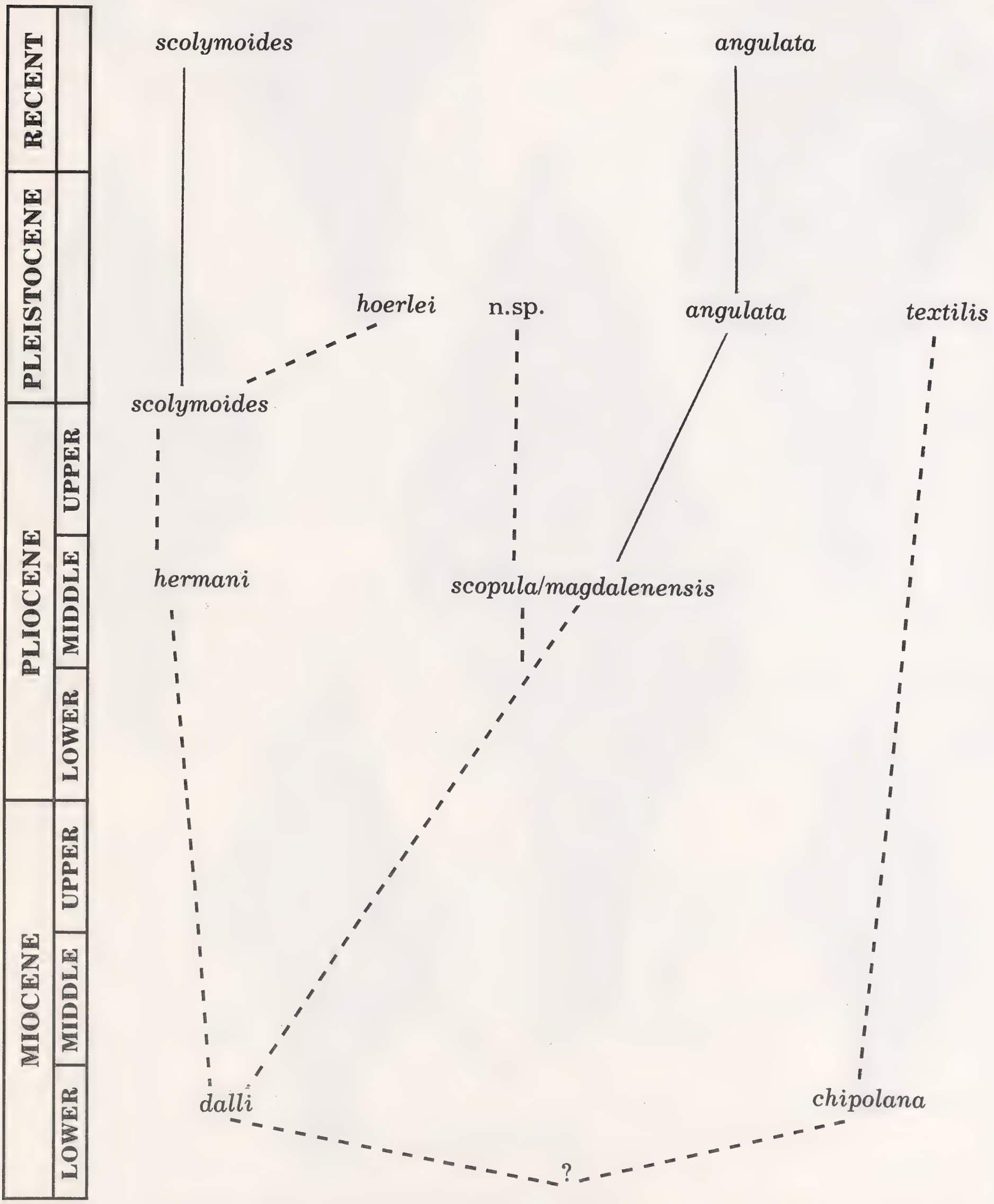

TABLE 1. GEOLOGIC DISTRIBUTION (REVISED) OF THE "*ANGULATA*" LINEAGE OF THE GENUS *TURBINELLA*, IN THE NEW WORLD.

ral" and "*laevigata*" lineages. However, these will be covered in a future paper on the genus *Turbinella* in the Dominican Republic, where there are representatives of both of the other groups.

II. SYSTEMATIC DESCRIPTION

Superfamily VOLUTACEA Rafinesque, 1815

Family TURBINELLINAE Swainson, 1840

Subfamily TURBINELLINAE Swainson, 1840

Genus TURBINELLA Lamarck, 1822

TURBINELLA HERMANI E. H. Vokes, n. sp.
Plate 1, figs. 1-3.

Description: Shell biconic; seven whorls in holotype; protoconch large, probably of four cylindrical whorls, usually truncated and plugged. Ornamentation beginning faintly with initially one median cord, others gradually appearing; by onset of axial ornamentation approximately seven spiral cords; this number remaining constant thereafter; smaller cords intercalated and increasing in size, with adult spiral ornamentation consisting of alternating major and minor cords, separated by tertiary threads; medial portion of adult whorl less ornamented, almost smooth. Axial ornamentation beginning on second or third teleoconch whorl with about ten narrow, sharply elongate ridges, decreasing in number to seven on third and subsequent whorls. First two or three ornamented whorls with moderately strong subsutural band, but subsequently evanescing and not especially conspicious on adult whorls. Axial ridges continuing as elongate ribs, not elevated at shoulder, with interspaces appearing "pinched-in." Aperture elongate, siphonal canal long and straight; columellar wall bearing three strong plaits.

Holotype: USNM 375457; height 113 mm, diameter 44.2 mm.

Type locality: TU 638, Agueguexquite Formation, road cut, pipeline cut, and quarry, on Mexico Highway 180, 14 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico.

Figured specimens: Fig. 1, USNM 375457 (holotype). Fig. 2, USNM 375458 (paratype A); height 17.3 mm, diameter 8.8 mm. Fig. 3, USNM 375459 (paratype B); height 72 mm, diameter 30.9 mm. All from locality TU 638. Other occurrence: locality TU 1046.

Discussion: Separation of the various members of the "*angulata*" lineage is almost impossible with a juvenile, as they are all very much alike, but it is simple with an adult shell. Thus, the adult of *T. hermani* may be distinguished from its more southern contemporaries, *T. scopula* and *T. magdalenensis*, by the lack of the strong "knobs" at the shoulder. However, its neighbor to the north, *T. scolymoides*, although similar in being weakly noded, is a more inflated shell with the nodes confined to the shoulder area of the whorl. The younger *T. hoerlei* is also closely related to *T. hermani* , but differs in having more numerous nodes, which also are confined to the shoulder area. Unlike both of these forms, *T. hermani* has the nodes developed from the shoulder to the base of the body whorl, with a deep concavity between these nodes extending across the smooth band encircling the main portion of the body whorl. One might say it has a rather emaciated appearance in contrast to the "plump" Florida species.

Given the stratigraphic constraints presently accepted, we assume that *T. hermani* is ancestral to *T. scolymoides*, which in turn gave rise to *T. hoerlei*, the three forms representing a completely different branch of the "*angulata*" lineage from the typical knobby forms, which began farther south and only moved into the Gulf area with the advent of warmer water, as discussed above.

Although the type material is relatively small, fragments in the type lot indicate an adult of a least 200 mm in height, as large as any of the other species of *Turbinella*. The species is moderately uncommon; the entire type lot consists, in addition to the figured specimens, only of broken columellas, or other pieces, and one additional juvenile.

This new species is named in honor of George Herman, Shell Oil Company. New Orleans, long time friend and "field-assistant," who collected the type specimen at great risk to life and limb.

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textilis, Fasciolaria GUPPY, 1873, Sci. Assoc. Trinidad, Proc., v. 2, p. 80; 1874, Geol. Mag. (Decade 2) v. 1, p. 410, pl. 16, fig. 5.

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V. LOCALITY DATA

201. Bermont Fm., spoil banks at pit just south of Belle Glade (at Belle Glade Camp), Palm Beach, Co., Florida.

519. Caloosahatchee Fm., Harney Pond Canal spoil banks, at Florida Highway 78, northwest side of Lake Okeechobee (NW ¼ Sec. 18, T40S, R33E), Glades Co., Florida.

638. Agueguexquite Fm., roadcut, pipeline cut, and quarry on Mexico Highway 180, 14 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico.

1046. Agueguexquite Fm., roadcuts on both sides of Mexico Highway 180, 7.5 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico. (This locality is that described in Perrilliat Montoya, 1960, Paleontologia Mexicana, no. 8, p. 5.)

1269. Cantaure Fm., series of arroyos about 500 yards south of "Casa Cantaure" [which is literally one house and which is about 400 yards south of older, now abandoned, house that was the "Casa Cantaure" of Jung, 1965, and others], 14 km (by road) west of Pueblo Nuevo, Paraguaná Peninsula, Venezuela.

R-75. Beach at Sisal, northwest corner of Yucatán Peninsula, Yucatán, Mexico.

October 31, 1984

THE GENUS *HARPA* (MOLLUSCA:GASTROPODA) IN THE NEW WORLD

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I. ABSTRACT

The name *Harpa americana* has been applied to every fossil *Harpa* specimen found in the New World. A second example of true *H. americana* from the Gurabo Formation, Dominican Republic, shows that none should be so referred and the form that occurs in the Agueguexquite Formation of Mexico is here named *H. isthmica,* n. sp. The examples taken from the Esmeraldas Formation of Ecuador are better referred to the living West Coast species *H. crenata.*

II. INTRODUCTION

The gastropod genus *Harpa* is a good example of the group Woodring termed "paciphiles," that is, present in the Tertiary of the Caribbean but now extinct there while still living on the eastern Pacific coast (see Woodring, 1966, p. 428, table 1). Until recently the entire known occurrence of the genus in the fossil record of the New World consisted of only two specimens: the types of *H. myrmia* Olsson, 1931, from the Oligocene of Peru; and *H. americana* Pilsbry, 1922, from the "Miocene" of Santo Domingo.

There are also in the New World several Eocene species assigned to *Eocithara* Fischer, 1883, once considered as a subgenus of *Harpa* but now recognized as an extinct genus. Rehder (1973) has summarized all of the harpid species, both fossil and Recent, of the entire world (not a formidable task, for there are fewer than 50 species total) and concluded that *Eocithara,* with 16 species-groups, is known from beds of Upper Paleocene to Middle Miocene age and geographically from Pakistan to Europe and in North America from Mississippi to California.

The genus *Harpa* s.s., which is distinguished by its larger size, multispiral conical protoconch, and expanded parietal callus, was considered by Rehder to include eleven living and five fossil species. Nine of the living forms are Indo-Pacific, as is one fossil. Only one Recent species is found in the eastern Atlantic (*H. doris* Röding = *H.rosea* Lamarck) and one in the eastern Pacific (*H. crenata* Swainson). Two fossil species come from the Miocene of Europe, and of course, the two Caribbean and eastern Pacific forms mentioned above as the New World fossil record.*

The only described species of *Harpa* in the Caribbean is that one originally referred by Gabb (1873, p. 214) to the West African *"H. rosea"* and subsequently renamed *H. americana* by Pilsbry (1922, p. 337). Known only to come from the Dominican Republic, with neither exact locality nor stratigraphic level being certain, and based upon a single incomplete shell, *H. americana* for some time remained the only name considered for any example of *Harpa* in the Neogene of the Caribbean. Thus, when Perrilliat Montoya (1960) monographed the "Middle Miocene" fauna of the Agueguexquite Formation of Mexico, the species of *Harpa,* which occurs in some numbers in the formation, was referred to *Harpa americana.* In 1979, Gibson-Smith and Gibson-Smith cited the *Harpa* they found in the Lower Miocene Cantaure Formation of Venezuela as *"Harpa* cf. *americana."* In 1981, Pitt attributed a specimen from the Pliocene beds at Esmeraldas, Ecuador, to *H. americana,*

*While this paper was in press the writer learned that David Dockery is in the process of describing a new species of *Harpa* from the Byram Marl (Vicksburgian – Lower Oligocene) of Mississippi (Miss. Dept. Nat. Res., Bur. Geol., Bull. 124, *in press*). Although there are a number of similarities to *Harpa* s.s. the resemblances to *Eocithara* are such that questions are raised as to whether the Mississippi form is truly to be referred to *Harpa* s.s. In particular, the inter-rib area is strongly cancellate and the protoconch seems to consist of only two rounded whorls. However, there is a thin callus that is not marginated and that does overlay the ribs of the previous whorl in typical *Harpa* fashion. This Oligocene species seems to be in transition between *Eocithara* and *Harpa* but it does not appear to be closely related to any subsequent species of *Harpa,* either in the Old World or the New. It probably represents a parallel development in *Eocithara* that led to a dead-end.

thereby extending not only the geologic range but also the geographic range.

However, the Cantaure specimens were soon removed from the synonymy of *H. americana* by Gibson-Smith and Gibson-Smith (1982) and referred instead to *H. myrmia* Olsson, which had the effect of shortening the geologic range considerably, as the so-called "Middle Miocene" Agueguexquite Formation is now known to be Middle Pliocene (Akers, 1972, p. 30) and the Dominican beds from whence *H. americana* is assumed to have been collected are now known to be latest Miocene-basal Pliocene in age (Saunders *et al.*, 1980, p. 157).

So long as the sole example of *H. americana* from the Dominican Republic was the incomplete type specimen we were not in a very good position to determine which, if either, of the remaining references should continue to be included with *H. americana*. But, after nine trips to the Dominican Republic, over a period of seven years, in which a total of over 150 localities were collected, at long last our perseverance was rewarded on the tenth trip with a second small example of *H. americana*.

This new specimen is not adult but that proved to be an advantage, for it does still have preserved the protoconch (see pl. 1, fig. 7b), which has four and one-half sharply conical whorls, and a noticeably cancellate shell surface (see pl. 1, figs. 7a and 8). This is in contrast to the Agueguexquite species, which has a protoconch of three and one-half rounded whorls and a nearly smooth adult shell. Therefore, the Mexican form is not to be referred to *H. americana* and it is described below as *H. isthmica*, n. sp.

Meanwhile, a second example of the Ecuadorian *"H. americana"* was recovered by Pitt (see pl. 1, fig. 5) and this shows the nature of the shoulder, missing in the first specimen. This new shell has a doubled row of shoulder spines, very like that in the living *H. crenata* and it is concluded that the Ecuadorian form is much nearer to that species than it is to the Dominican or Mexican one.

Thus, in the Caribbean we now have three species of *Harpa:* the youngest being *H. isthmica*, n. sp., most like the Recent West African *H. doris; H. americana*, from the Dominican Mio-Pliocene, probably ancestral to the Recent West Coast *H. cre-*

PLATE 1

Figures

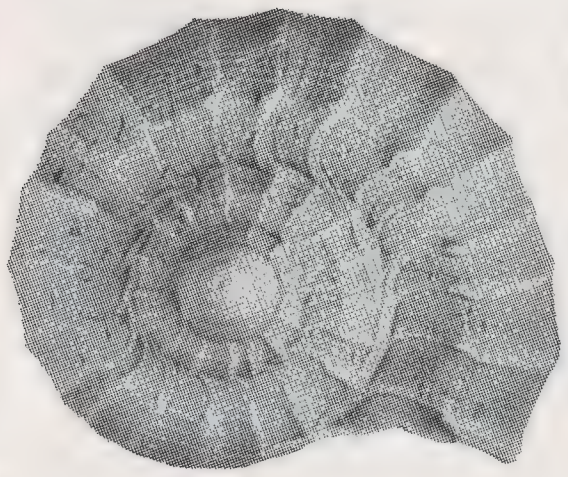
1 - 3. *Harpa isthmica* Vokes, n. sp.
   1. (× 1½) USNM 377402 (holotype); height 32.8 mm, diameter 22.0 mm.
      Locality: TU 1046. Agueguexquite Fm., Veracruz, Mexico.
   2. (2a - × 3; 2b - × 10; 2c - × 2) USNM 377403 (paratype A); height 21.3 mm, diameter 12.4 mm.
      Locality: TU 638. Agueguexquite Fm., Veracruz, Mexico.
   3. (× 1½) USNM 377404 (paratype B); height of fragment 36.5 mm, diameter of fragment 30.4 mm.
      Locality: TU 1046. Agueguexquite Fm., Veracruz, Mexico.
4. *Harpa doris* Röding
   (× 1) Tulane Collection; height 55.8 mm, diameter 33.2 mm.
   Locality: Ivory Coast, West Africa.

5, 6. *Harpa crenata* Swainson
   5. (× 1½) CAS 60735; height 39.0 mm, diameter (incomplete) 19.8 mm.
      Locality: Quebrada Camerones (=TU 1397). Esmeraldas Formation, Prov. Esmeraldas, Ecuador.
   6. (× 1) Tulane Collection; height 55.0 mm, diameter 35.5 mm.
      Locality: Mazatlán, Sinaloa, Mexico (fishermen).

7, 8. *Harpa americana* Pilsbry
   7. (7a - × 2; 7b - × 10) USNM 377397; height 23.0 mm, diameter 14.3 mm.
      Locality: TU 1444. Gurabo Formation, Dominican Republic.
   8. (× 1½) ANSP 4061 (holotype); height 33.3 mm, diameter 19.4 mm.
      Locality: Unknown, Dominican Republic.

1a

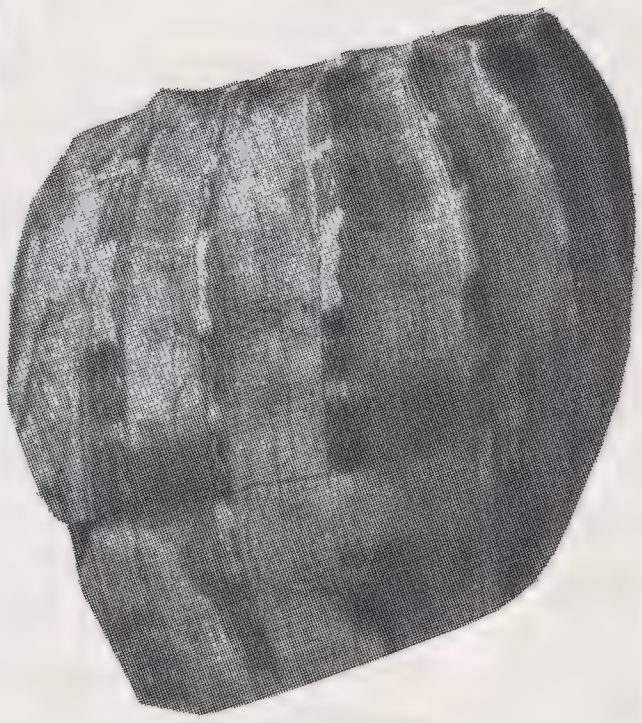
1b


2a

2b

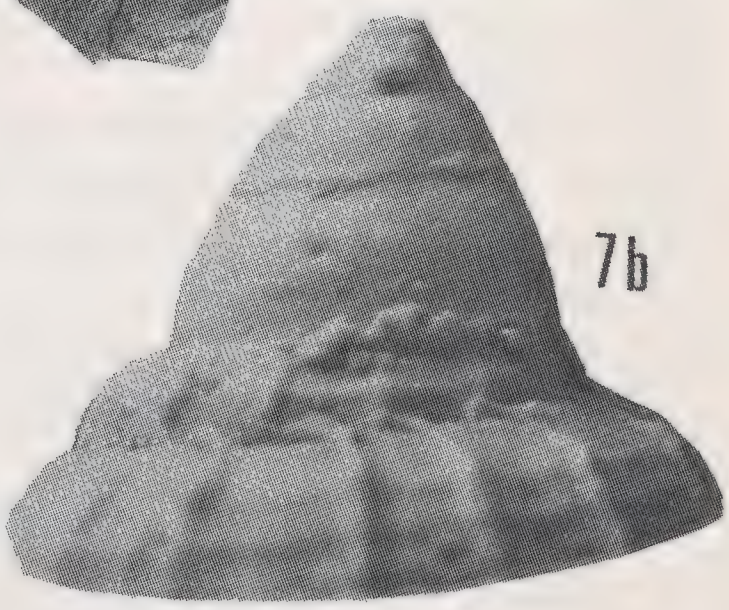
2c

4


3

8

7a


7b

5

6

PLATE 1

nata and its mid-Pliocene relative in Ecuador; and in the early Miocene of Venezuela, a species which may or may not be the same as *H. myrmia,* from the Oligocene of Peru. The latter question cannot be resolved unless more material of the Oligocene form is recovered, for the unique type specimen is woefully incomplete. But, on the basis of the material presently available, there is no reason why the Venezuelan form is not to be referred to *H. myrmia*. Both are marked by having the suture crossed by extensions of the ribs, a feature that is not developed in any other species of *Harpa* now known.

Although Gibson-Smith and Gibson-Smith (1982, p. 59) suggested that the Venezuelan species might prove to be ancestral to the *H. crenata* line, the nature of the varices would seem to indicate this is not the case. For the present we will continue to assume that an as-yet unknown ancestor in the early Neogene gave rise to both *H. doris* and *H. americana*. In the New World, *H. americana* then gave rise to both the Mexican *H. isthmica* and the Ecuadorian *H. crenata,* the latter in turn persisting into the Recent fauna. The more southern lineage of *H. myrmia* is presumed to have left no descendants.

III. SYSTEMATIC DESCRIPTIONS

Superfamily VOLUTACEA Rafinesque, 1815

Family HARPIDAE Bronn, 1849

Genus HARPA Röding, 1798

Harpa RÖDING, 1798, Mus. Boltenianum, p. 179.

Type species (by tautonony): *Harpa nobilis* Röding = *Buccinum harpa* Linnaeus.

HARPA MYRMIA Olsson

Harpa myrmia OLSSON, 1931, Bulls. Amer. Paleontology, v. 17, no. 63, p. 114(21), pl. 32(20), fig. 7.

[?] *Harpa* cf. *americana* Pilsbry. GIBSON-SMITH and GIBSON-SMITH, 1979, GEOS, no. 24, p. 22.

[?] *Harpa myrmia* Olsson. GIBSON-SMITH and GIBSON-SMITH, 1982, Tulane Stud. Geol. Paleont., v. 17, no. 2, p. 57, text figs. 1-3.

Discussion: As noted above, the specimens from the Lower Miocene Cantaure Formation of the Paraguaná Peninsula, Venezuela, may or may not be referable to *H. myrmia,* described from the Lower Oligocene Chira Formation of northernmost Peru. Both forms have extremely heavy axial ribs, which cross over the suture, forming a series of lamellar flanges across the subsutural ramp. The surface texture of the shell is cancellate between the smooth axial ribs. The parietal callus is somewhat marginate and suggests that this line may be independently derived from the ancestral *Eocithara* line. In particular, Rehder (1973, p. 231, pl. 204) cites a specimen from the Middle Eocene of Texas (reproduced from Palmer, 1937, pl. 65, fig. 6) which seems very close to *H. myrmia*.

HARPA AMERICANA Pilsbry

Plate 1, figs. 7, 8

Harpa rosea Lamarck. GABB, 1873, Amer. Phil. Soc., Trans., (N. S.) v. 15, p. 214 (*not* of Lamarck).

Harpa americana PILSBRY, 1922, Acad. Nat. Sci. Phila., Proc., v. 73, p. 337, pl. 23, fig. 13.

NOT *Harpa americana* Pilsbry. PERRILLIAT MONTOYA, 1960, Paleontologia Mexicana, no. 8, p. 24, pl. 3, figs. 18, 19 (= *H. isthmica,* n. sp.).

Harpa americana Pilsbry. REHDER, 1973, Indo-Pacific Moll., v. 3, no. 16, p. 257, pl. 228.

NOT *Harpa* cf. *americana* Pilsbry. GIBSON-SMITH and GIBSON-SMITH, 1979, GEOS, no. 24, p. 22 (? = *H. myrmia* Olsson).

NOT *Harpa americana* Pilsbry. PITT, 1981, Tulane Stud. Geol. Paleont., v. 16, no. 4, p. 155, text fig. 1 (? = *H. crenata* Swainson).

Discussion: This species was described without locality or stratigraphic horizon, but now a single specimen has been collected at TU 1444, in the basal beds of the Gurabo Formation, regarded as uppermost Miocene or basal Pliocene in age.

In many ways the Dominican species is more similar to the West American *H. crenata* than it is to the West African *H. doris*. In both of the New World species the axial ribs are extremely narrow and low, being little more than raised ridges on the shell surface. Both have a series of pronounced nodes on these ribs, anterior to the spine at the shoulder. The main difference between the two forms, in addition to the protoconchs, is the more inflated whorl outline

in *H. crenata,* in which the secondary nodes anterior to the shoulder become as prominent as the shoulder spines, giving a "double-shouldered" aspect to the shell.

As the Mexican *H. isthmica* n. sp., and the Pacific *H. crenata* are contemporaries (both mid-Pliocene) they are assumed to represent parallel descent from the earlier *H. americana.* The Mexican species moved in the direction of heavier ribs and a smoother shell while the Pacific form moved toward a more inflated shape.

HARPA ISTHMICA E. H. Vokes, n. sp.
Plate 1, figs. 1-3

Harpa americana Pilsbry. PERRILLIAT MONTOYA, 1960, Paleontologia Mexicana, no. 8, p. 24, pl. 3, figs. 18, 19 (*not* of Pilsbry).

Harpa americana Pilsbry. REHDER, 1973, Indo-Pacific Moll., v. 3, no. 16, p. 258 (in part, reference to Verzcruz specimens only).

Description: Shell of moderate size, with (?) five teleoconch whorls in adult (three or four in all specimens seen), rapidly increasing in size; protoconch of three and one-half smooth, inflated whorls, tilted slightly at an angle to main axis of shell, a small keel developed at periphery. Spiral ornamentation on early post-nuclear whorls of flat-topped bands, alternating in strength, about four pairs on first whorl, increasing in number but diminishing in strength with growth, body whorl covered with numerous (approximately five pairs in one mm) faint spiral bands, combining with even weaker axial growth lines to give a linen-like texture to shell surface, stronger in young specimens, evanescing to an almost smooth surface on larger specimens. Axial ornamentation beginning on first post-nuclear whorl with 14 to 19, but usually 16, narrow, straight riblets, on second whorl number increasing to between 17 and 20, but always more than on first whorl; third and successive whorls having either the same or slightly fewer ribs than the second, varying from 15 to 21 in number; initially no angulation at shoulder, beginning faintly on second and prominent by third whorl, with a small abaperaturally directed spine at each rib; anteriorly a series of extremely weak nodes marking the crossing of other spiral bands. Aperture elongate, parietal wall, including siphonal fasciole, covered by a thin callus wash; outer lip somewhat flaring at posterior end; recurved anal notch at posterior end with a callus becoming more pronounced in each successive whorl, overlapping the suture and previous whorl to an increasing degree, entire area anterior to shoulder spines covered by third teleoconch whorl. Color pattern similar to that of *Harpa doris,* with zigzag lines between ribs, overlain by irregular larger blotches overriding the ribs.

Holotype: USNM 377402; height 32.8 mm, diameter 22.0 mm.

Type locality: TU 1046, Agueguexquite Formation, roadcuts on either side of Mexico Highway 180, 12 km (7.5 mi) east of junction with side road into Coatzacoalcos, Veracruz, Mexico (the same locality as Perrilliat Montoya's 180 m east of Km 11 on highway "Paralelo 18," which goes from Coatzacoalcos to Mascupana).

Paratypes: A) USNM 377403; height 21.3 mm, diameter 12.4 mm; locality TU 638; B) USNM 377404 (fragment); height 36.5, diameter 30.4 mm; locality TU 1046.

Discussion: As noted in the introduction, the form cited by Perrilliat Montoya (1960, p. 24) as *"Harpa americana"* is not that species. It differs from *H. americana* in having a more mammillate protoconch, with three and one-half whorls, in contrast to the conical, four and one-half whorl protoconch of *H. americana.* On the basis of the two specimens as yet known of *H. americana* the new species also has more numerous and heavier varices, and a smoother surface in the adult shell. The Mexican species is closer to the living West African *H. doris* Röding than is *H. americana* (which was originally identified as the African form), having a nearly identical protoconch and the smooth shell of the living form. The new species, however, differs in having more numerous ribs, which are much narrower than those in *H. doris.* In addition, some specimens, although not all (for example the one here figured, pl. 1, fig. 4), of *H. doris* have stronger secondary nodes on the ribs, anterior to the shoulder spine.

The number of lamellar axial ribs is extremely variable in this species, but the pattern of increase then decrease in successive whorls seems constant. Table 1 shows the number of ribs in a few paratype specimens. There are numerous examples of this species in the Tulane collections from the Middle Pliocene (Neogene zone N. 20) Agueguexquite Formation (TU 638 – 24 examples; TU 1046–14; TU 1347–2) but

TABLE 1
Number of axial ribs per whorl in *H. isthmica*

Whorl Number	TU 1046				TU 638		TU 1347
First	16	16	16	19	15	–	16
Second	19	18	18	20	19	19	19
Third	19	15	17	17	17	23	19
Fourth	–	–	–	–	17	21	–

most are somewhat broken and battered, suggesting that the species lived in a relatively shallow habitat. This is further corroborated by the fact that it has been taken nowhere else, even in localities that are geographically very close to these but slightly older (N. 19, "Concepción Inferior") and of a somewhat deeper facies.

Although a majority of the specimens are less than 40 mm in height, the fragmentary paratype illustrated to show the color pattern (pl. 1, fig. 3) indicates a maximum height of at least 50 mm, or approximately the same size as *H. doris*. The color pattern is also very close to that of *H. doris*, with the exception that the larger blotches override the ribs, rather than just being between the ribs, and there is no trace of the thin dark line that marks the ribs in *H. doris*. An attempt was made to bring out the color pattern in the fossils by means of ultra-violet light but it was not successful. The color seen in the paratype is natural; the holotype also shows an original color pattern but has been whitened here to bring out details of ornamentation.

HARPA CRENATA Swainson
Plate 1, figs. 2, 5; text fig. 1

Harpa crenata SWAINSON, 1822, Catalogue Shell Coll. Bligh, Appendix, p. 5.

Harpa crenata Swainson. KEEN, 1958, Sea Shells Trop. West America, ed. 1, p. 431, fig. 663; 1971, Sea Shells Trop. West America, ed. 2, p. 620, fig. 1357.

[?] *Harpa americana* Pilsbry. PITT, 1981, Tulane Stud. Geol. Paleont., v. 16, no. 4, p. 155, text fig. 1 (*not* of Pilsbry).

Discussion: The specimen figured by Pitt (1981, text fig. 1) from the Pliocene Esmeraldas Formation of Ecuador is lacking the shoulder area and, thus, does not show the three-pointed angulation characteristic of the Recent *H. crenata*. However, a second example (pl. 1, fig. 5) taken later by

TABLE 2
Number of axial ribs per whorl in *H. americana*

Whorl Number	Holotype	TU 1444
First	13	15
Second	17	17
Third	?12	17

Mr. Pitt, and now in the collections of the California Academy of Sciences, does show a tendency toward this ornamentation, as well as the linen-like texture of the shell surface of this species. The Recent examples of *H. crenata* become very inflated in the adult stage (pl. 1, fig. 6) but juvenile shells have an outline virtually identical to that of the Esmeraldas example (compare text fig. 1A and 1B).

Neither of the Esmeraldas specimens has a perfect protoconch but the smaller example seems to show a mammillate protoconch of three and one-half whorls, which is identical to that of the Recent specimens of *H. crenata*. Therefore, on the basis of the two specimens currently available, there is no reason that the Esmeraldas form is not to be considered the same as the living form; it may be a stratigraphic subspecies, at best.

IV. ACKNOWLEDGMENTS

The writer is grateful to Mr. William Pitt, Research Associate of the California Academy of Sciences, and the Academy itself, for the loan of the two specimens from the Esmeraldas Formation utilized in this study. In addition, the Academy of Natural Sciences of Philadelphia kindly loaned the holotype of *H. americana*. Financing of the trip to the Dominican Republic, which finally produced a second example of *H. americana* was provided by the Mesoamerican Ecology Institute of Tulane University.

V. LOCALITY DATA

The following are Tulane University locality numbers:

638. Agueguexquite Fm., roadcut, pipeline cut, and quarry on Mexico Highway 180, 14 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico.

1046. Agueguexquite Fm., roadcuts on both sides of Mexico Highway 180, 7.5 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico. (This locality is that described in Perrilliat Montoya, 1960, Paleontologia Mexicana, No. 8, p. 5.)

1397. Esmeraldas Fm., Quebrada Camerones, cut bank on east side of canyon, which is at east edge of village of Camerones, 20 km (by road) east of highway bridge over Rio Esmeraldas, at Esmeraldas, or approximately 5 km east of mouth of Rio Esmeraldas, Prov. of Esmeraldas, Ecuador (a shallow-water gravity flow into deep water Esmeraldas Fm.).

1444. Gurabo Fm., Rio Yaque del Norte, east bank, at Lopez, approximately 0.5 km upstream from mouth of Arroyo Lopez, between middle and lower hard limestone ledges.

1347. Agueguexquite Fm., pipeline cut, which parallels Mexico Highway 180, 7.5 miles east of junction with side road into Coatzacoalcos, Veracruz, Mexico (due north of TU 1046).

R-492. Jaco Beach, Pacific coast, south of Puntarenas, Costa Rica.

Text figure 1. Outline of shell shape in: A) *Harpa crenata* Swainson, TU R-492; and B) *Harpa* cf. *crenata*, Esmeraldas Fm., Ecuador. Both ×1.

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October 31, 1984

REVIEW

THE UNITED STATES ENERGY ATLAS, by David J. Cuff and William J. Young. Published by Macmillan Publishing Co., Inc., New York, 1980, viii + 416 pp., illus., $75.00

This volume locates and describes the amount and distribution of all energy sources, from non-renewable resources such as coal, petroleum, natural gas, and nuclear fuels, to renewable resources such as solar power, windpower, and biomass. Organized in eleven chapters and profusely illustrated, the book is primarily concerned with illustrating the quantities and qualities of America's resources with comparative data analyses by state and region, consumption and transportation patterns, the position of the United States in world energy supplies, and practical evaluations of solar energy heating versus oil and gas heating, etc.

Over 200 maps, 150 graphs and figures, and dozens of diagrams and halftones are included along with a glossary and index. The nine by twelve inch format permits a pleasing appearance and useful scale for the illustrative maps and figures.

—H.C.S.

A REVISION OF THE TEREBRID GASTROPODS OF THE MARE FORMATION, CABO BLANCO, VENEZUELA

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ABSTRACT

Three taxa from the late Pliocene Mare Formation, Venezuela, are considered. *Strioterebrum trispiralis* (Weisbord, 1962) is made a synonym of *S. quadrispiralis* (Weisbord, 1962) and the form assigned by Weisbord (1962) to *Terebra (Strioterebrum) gatunensis kugleri* Rutsch, 1934, from the early Pliocene Punta Gavilan Formation, Venezuela, later reassigned by Woodring (1964) to *S. dislocatum* (Say), is described as a new species: *S. weisbordi*. Both *S. quadrispiralis* and *S. weisbordi* survive in Venezuelan waters. Finally, a new species is described from the Venezuelan Recent: *S. angelli*.

INTRODUCTION

Weisbord (1962) cited three taxa in the subgenus *Terebra (Strioterebrum)* from the late Pliocene Mare Formation, Cabo Blanco, Venezuela. One was assigned to *T. (S.) gatunensis kugleri* Rutsch, 1934, from the early Pliocene Punta Gavilan Formation, Falcón State, Venezuela. The Punta Gavilan form, however, was later made a junior synonym of *S. spiriferum* (Dall, 1895) from the Gatun Formation, Panamá, by Woodring (1970, p. 409) who, at the same time, recognized that the Mare form was distinct, reassigning it to *S. dislocatum* (Say, 1822). This last is known from the early Miocene to Recent in Florida and today ranges from Maryland to Texas, the West Indies and Brazil, but also on the west coast from California to Panamá (Abbott 1974, p. 259; Keen 1971, p. 674). However, the Mare form, which still survives in Venezuela, differs from *S. dislocatum* and is described here as a new species: *Strioterebrum weisbordi* n. sp.

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The other two taxa cited by Weisbord (1962) were: *T. (S.) trispiralis* n. sp. and *T. (S.) quadrispiralis* n. sp. However, with better material available, it is clear that they represent a single taxon and, although the former has page preference, it is referred here to *S. quadrispiralis* as being more correctly descriptive. It also occurs in the Venezuelan Recent.

Lastly, a new species from the Venezuelan Recent, formerly referred to *S. trispiralis* and *S. quadrispiralis* by Petuch (1981, p. 337) is described here as *Strioterebrum angelli* n. sp.

It might be added that the Mare fauna was reviewed briefly by Gibson-Smith and Gibson-Smith (1979, p. 24), the number of taxa still surviving in Venezuela being greatly increased. Two more can now be added.

Family TEREBRIDAE
Genus STRIOTEREBRUM Sacco

Strioterebrum SACCO, 1891, I Molluschi dei terreni terziarii de Piemonte e della Liguria, pt. 10, p. 33.
Type species (by original designation): *Terebra basteroti* Nyst.

STRIOTEREBRUM WEISBORDI
Gibson-Smith and Gibson-Smith, n. sp.
Plate 1, Figures 1, 2

Terebra (Strioterebrum) gatunensis kugleri Rutsch, 1934. WEISBORD, 1962, Bulls. Amer. Paleontology, v. 42, no. 193, p. 428, pl. 40, figs. 12, 13; pl. 45, figs, 24, 25. PETUCH, 1981, Malacologia, v. 20, no. 2, p. 336, figs. 99, 100 (both *non* Rutsch).

Strioterebrum dislocatum (Say, 1822). WOODRING, 1970, U.S. Geol. Surv., Prof. Paper 306-D, p. 413 (under *S. indocayapum* Olsson) (*non* Say.)

Description: "The Cabo Blanco shell referred to *T. kugleri* is of medium size, slender, the spire acuminate, the apex often slightly bent, the angle of spire below the apex about 15 degrees. Fully grown, the species has nearly 18 whorls in

all, the nucleus consisting of 1½ or 2 of them. Nucleus smooth, subhyaline, the tip fused and indistinct, the initial turn full, a little offset from the last which is bulbous and larger than the first post-nuclear whorl, and is defined from the conch by the appearance of axial riblets. First post-nuclear whorl flat-sided, sculptured by 14 to 18 curved axial ribs extending from suture to suture with four or five spiral grooves in the interspaces. Subsequent whorls are provided with a collar immediately below the suture the collar marked with subequal longitudinal riblets. Below the collar the sculpture consists of rather narrow, subequal axial cords and lower spiral ridges, the intercepts beaded, the general pattern subreticulate. Mature shells have an average of 33 axial cords on the penultimate whorl, but there may be as many as 38 and as few as 30, one specimen having only 25. Generally there are four spiral ridges below the collar, but here again the number may vary; one specimen has but three and several have five or six. The spacing of the spiral ridges is also variable. On some of the specimens the ridges are more or less equal, on others the interspace is wider below the first or second spiral ridge. On a number of specimens the posterior spiral ridges are stronger than the anterior, but this is not constant. The subsutural collar is prominent and broad, occupying a little over a third of the whorl; it is crenulated by broad axial riblets or folds about equal in number to the axial cords below but larger than those. The collar is thicker posteriorily and projects slightly beyond the preceding whorl. On later whorls, the furrow below the collar is fairly deep and wide, but on the earliest whorls, the space below the collar is represented by a fine groove. Surface covered with numerous axial growth striae. Sutures narrowly impressed, hardly distinguishable. Aperture sinuously lenticular. Outer lip broken back on all specimens. Columella with two strong folds of about the same size; the lower one forms the margin of the canal. Parietal wall with a thin covering of enamel, rather deeply excavated above the posterior of the columellar folds. Siphonal fasciole flattish to undulatory, built up of arched incrementals, bordered by a strongly keeled ridge which continues around to form an emargination on the side of the terminal notch. Above the keel, the base is severely contracted into a deep broad furrow. Last whorl with an average of 13 coarse nodulous spiral ribs of unequal size, and nearly obsolescent axial cords, the ribs usually present in the furrow at the base. Anterior canal short, broad, and deep, recurved backward at the extremity, the siphonal notch large and broadly U-shaped." (Weisbord, 1962)

Addendum to description: Recent specimens are banded in brown with darker flammules and a narrow white band below mid-whorl; nodes of subsutural collar alternating white and brown; aperture dark brown.

Holotype: PRI 26324, as illustrated by Weisbord (1962, pl. 40, figs. 12, 13); height 38.3 mm, diameter 9.5 mm.

Type locality: Lower Mare Formation, Cabo Blanco Venezuela; late Pliocene.

Paratypes: USNM 236013, NHMB H 17098; BM(NH) 21461-5; Universidad Central de Venezuela, UCVG 7064.

PLATE 1

Figures

1, 2. *Strioterebrum weisbordi* Gibson-Smith and Gibson-Smith, n.sp.
   1. Paratype, USNM 256013; height 48.3 mm, diameter 11.0 mm.
      Locality: Mare Formation, Cabo Blanco, Venezuela.
   2. NHMB H17098; height 38.6 mm, diameter 9.2 mm.
      Locality: Punta Mangle, Isla Margarita, Venezuela. Recent.

3. *Strioterebrum spiriferum* (Dall, 1895).
   3. NHMB H17100; height 49.0 mm, diameter 11.6 mm.
      Locality: Punta Gavilan Formation, Falcón State, Venezuela.

4, 5. *Strioterebrum quadrispiralis* (Weisbord).
   4. PRI 8228; height 24.8 mm, diameter 5.5 mm.
      Locality: Mare Formation, Cabo Blanco, Venezuela.
   5. NHMB H17101; height 16.2 mm, diameter 3.7 mm.
      Locality: Recent, Punta Moron, Carabobo State, Venezuela.

6, 7. *Strioterebrum angelli* Gibson-Smith and Gibson-Smith, n.sp.
   6. Holotype, USNM 784720; height 15.4 mm, diameter 4.1 mm.
   7. Same, whitened.

(All illustrations magnified × 7)

PLATE 1

Range: Also Recent along the north coast of Venezuela from the Golfo de Venezuela to Isla Margarita.

Remarks: There are 435 specimens available in the collections of the authors. A single, worn specimen was recorded by Weisbord *(loc. cit.)* from the Maiquetia Member, Playa Grande Formation, at Punta Gorda (locality W-23 = GS-7-CB). However, as stated by Gibson-Smith and Gibson-Smith (1979, p. 24) this locality also pertains to the Mare Formation. The Recent suite consists of 26 specimens found mainly in beach drift, but also at depths down to 15 meters. For comparison there are 54 topotypes of *S. spiriferum* from Punta Gavilan and 37 specimens of *S. dislocatum* from Florida.

Comparisons: Strioterebrum weisbordi n. sp. differs from *S. spiriferum* (Fig. 3) in being more tightly coiled in the adult, with lower whorls; the spiral groove below the subsutural cord is wider and across it the axial ribs are obsolescent. The columellar fold in *S. weisbordi* is strongly bipartite; whereas, in *S. spiriferum* it is broad and low, possibly representing two completely fused folds. The base of the whorl in *S. weisbordi* is more abruptly constricted, resulting in a shorter more sharply recurved, anterior canal. Finally, *S. weisbordi* is smaller than *S. spiriferum,* reaching a height of 65 *versus* 95 mm. Weisbord *(loc. cit.)* noted a similarity between *S. weisbordi* and *S. dislocatum,* but found that "the Cabo Blanco shells have a greater number of axial cords, the groove below the subsutural collar is more pronounced and the two columellar folds are not fused as they are on *T. dislocata.*" It can be added that in *S. dislocatum* the subsutural collar is wider, occupying more of the whorl height, and the attendant, narrower groove is crossed by the reduced axial ribs.

STRIOTEREBRUM QUADRISPIRALIS Weisbord
Plate 1, Figures 4, 5

Terebra (Strioterebrum) quadrispiralis WEISBORD, 1962, Bulls. Amer. Paleontology v. 42, no. 193, p. 431, pl. 41, figs. 1-4.

Terebra (Strioterebrum) trispiralis WEISBORD, 1962, Bulls. Amer. Paleontology, v. 42, no. 193, p. 430, pl. 40, figs. 14, 15.

Strioterebrum bowdenensis Woodring, 1928. PETUCH, 1981, Malacologia, v. 20, no. 2, p. 36, fig. 98 *(non* Woodring).

NOT *Strioterebrum quadrispiralis* Weisbord. PETUCH, 1981, Malacologia, v. 20, no. 2, p. 337, figs. 103, 104 (= *S. angelli* n.sp.).

NOT *Strioterebrum trispiralis* Weisbord. PETUCH, 1981, Malacologia, v. 20, no. 2, p. 337, figs. 105, 106 (= *S. angelli* n.sp.).

Addendum to description: Shell reaching a height of 26.4 mm with a diameter of 6.6 mm. Protoconch of one and one-fourth whorls, teleoconch of 11 to 12 whorls. Number of spiral cords varying between three and eight. In Recent specimens the shell is orange-brown in colour with a lighter band at the middle of the whorl, many specimens having faded (?) to white.

Remarks: With a suite of 61 Mare specimens available it is clear that *S. trispiralis* and *S. quadrispiralis* are the same. Of 41 adult specimens, three have three spiral cords, 17 have four and 21 have five to eight spiral cords. They are referred to *S. quadrispiralis* as being more representative of this taxon, rather than to *S. trispiralis* which has page preference. A Recent suite of 118 specimens comes from ten localities along the north coast of Venezuela between Adicora, Paraguaná Peninsula, and Punta Mangle, Isla Margarita; most came from beach drift, but some are from a depth of 55 meters in a seafloor sample from a Maraven S.A. drilling location in the Ensenada de Barcelona (Well EBC-1-X; coordinates: N.10° 18′ 28″, W.65° 32′ 00″). The Recent form is somewhat smaller than the fossil, maximum heights being 22.3 and 26.4 mm with maximum diameters of 4.8 and 6.6 mm, respectively; in both there is a variation in the degree of stoutness. Two Recent specimens from the Golfo Triste, Venezuela, were assigned by Petuch (1981, p. 336, fig. 98) to *S. bowdenensis* (Woodring, 1928) from the early Pleistocene Bowden Formation, Jamaica; they are specimens of *S. quadrispiralis.* The protoconch of *S. bowdenensis* is of two to two and one-half whorls and the diameter of a large shell quoted by Woodring (1928, p. 138) is 12.2 mm at a broken height of 28.1 mm, indicating a very much larger shell than is *S. quadrispiralis.* The homologue of *S. quadrispiralis* in Florida seems to be *S. pro-*

texta (Conrad, 1845); we have found no description of its protoconch, but the spire whorls are said to be slightly concave (Abbott, 1974, p. 260) and its purplish-black, or ashy to dark purple, colour is also distinct. The ancestor of *S. quadrispiralis* is believed to be *S. meesmanni* (Rutsch, 1934) from the early Pliocene Punta Gavilan Formation, Falcón State, but that is more coarsely sculptured, with heavily beaded axial ribs, as seen in 15 topotypes.

STRIOTEREBRUM ANGELLI
Gibson-Smith and Gibson-Smith, n. sp.
Plate 1, Figures 6, 7.

Strioterebrum quadrispiralis (Weisbord, 1962). PETUCH, 1981, Malacologia, v. 20, no. 2, p. 337, figs. 103, 104 (*non* Weisbord).

Strioterebrum trispiralis (Weisbord, 1962). PETUCH, 1981, Malacologia, v. 20, no. 2, p. 337, figs. 105, 106 (*non* Weisbord).

?*Strioterebrum ischna* (Woodring, 1928), PETUCH, 1981, Malacologia, v. 20, no. 2, p. 336, figs. 101, 102.

Description: Shell small, somewhat stubby for the genus, reaching a height of 15 mm. Protoconch of one and one-half smooth, brown whorls; ten sculptured whorls. Whorls bulging about the middle, the periphery close to anterior suture. A strongly noded subsutural cord delimited by a narrow, deep sulcus crossed by the reduced axial ribs. Axial ribs strong, sharp, opisthocyrt, numbering 13 to 15 with wider interspaces. Two to five flat spiral cords, with more on the base, often weak to obsolescent over the middle of the whorl and failing to node the axial ribs. Shell surface covered in microscopic, crowded spiral striae. No columellar fold. Colour a dark purplish brown with a lighter ashy band about the whorl middle; the nodes of the subsutural collar and the crests of the axial ribs also sometimes ashy. Columella brown and inside of aperture a translucent brown.

Holotype: USNM 784720; height 15.4 mm, diameter 4.2 mm.

Type locality: Recent, Punta Mangle, Isla Margarita, Venezuela.

Paratypes: AMNH 202289: BM(NH); NHMB H 17099: Universidad Central de Venezuela, UCVG 7065.

Remarks: There are some 900 paratypes of *Strioterebrum angelli* n.sp. from a number of north coast localities. Of these, 700 came from suction-dredge spoil at Punta Mangle, Isla Margarita; they occur also on a mud flat with *Thalassia* at adjacent Punta de Piedras. None were recovered in the carbonate province of the offshore islands; they prefer, seemingly, a muddier environment. The name records our appreciation of much help, including donation of material, given by marine biologist Charles Angell, at one time in charge of oyster and shrimp culture at the Estación de Investigaciones Marinas, Punta de Piedras, Isla Margarita.

Comparisons: Although assigned by Petuch (1981, p. 337), using our material, to *S. trispiralis* Weisbord and *S. quadrispiralis* Weisbord (redefined earlier as one species under *S. quadrispiralis), S. angelli* is not closely related and is little over half the size. Nor do there seem to be any other closely related Recent taxa. Its ancestor may be *Strioterebrum brechincastrensis* (Rutsch, 1942) from the early Pliocene Springvale Formation, Trinidad; it has similar bulging whorls and strong, opisthocyrt axial ribs, but it is twice the size of *S. angelli,* reaching a height of almost 30 mm. An undescribed form related to *S. brechincastrensis* is present in the early Pliocene Punta Gavilan Formation. The status of the form assigned by Petuch (1981, pp. 336, 337) to *Strioterebrum ischna* (Woodring, 1928) from the early Pleistocene Bowden Formation, Jamaica, is problematical; it occurs together with *S. angelli* at Adicora, Paraguaná Peninsula; with its bulging whorls and strong opisthocyrt axials, it has much the appearance of that species. *S. ischna* on the other hand is smaller and slimmer, its whorls less convex and it virtually lacks a subsutural cord, giving to some specimens a *Hastula*-like appearance (Woodring, 1928, p. 136). This form from Adicora may be no more than juvenile *S. angelli.*

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REVIEW

DISTRIBUTION OF SHALLOW-WATER MARINE MOLLUSCA, YUCATAN PENINSULA, MEXICO, by Harold E. Vokes, and Emily H. Vokes. Published by Middle American Research Institute and Mesoamerican Ecology Institute of Tulane University, New Orleans, 1983, viii + 183 pp., illus., atlas of 50 pls., paper $21.50 (including postage and handling)

This monograph presents the data compiled during the past twenty-five years by the late E. Wyllys Andrews IV and by Harold and Emily Vokes, who joined him in this project in 1964. When Dr. Andrews became ill and it became apparent that he would not survive, the doctors Vokes promised him that they would see their combined efforts through to completion. This handsomely illustrated volume recording 769 identified species from 99 localities and their distribution within seven ecological provinces along the coasts of Yucatan amply fulfills their promise. The book is dedicated to Bill Andrews.

Yucatan, a quadrangular limestone platform, occupies an unique position geographically and ecologically. Its eastern margin fronts on the Caribbean Sea and drops steeply into deep waters; its northern and western margins are on the Gulf of Mexico and have broader and shoaler shelf areas known as the Yucatan Bank. Further, the eastern margin is bordered by a nearly continuous series of coral barrier reefs, but coral growth is confined to the outer reaches of the Yucatan Bank and consists of relatively small patch reefs. The waters off the east coast are deep blue and mud-free, those off the northern and western coasts are milky green reflecting the rather high content of suspended "lime-mud" sediments. These physical differences contribute to the striking differences in the faunas and ecological environments of the eastern coast compared with the northern and western coasts. These, and other geological, geographical, and ecological features are described and explained in the text. This monograph is an extremely important contribution to the knowledge of Recent molluscan distributions and ecology and is highly recommended to all readers interested in this field of study.

The volume is number 54 of the prestigious *Publications* series of the Middle American Research Institute. It also comprises Monograph 1 of Mesoamerican Ecology Institute, a new series. Both institutes were among those institutions who supported the research recorded therein. Publication 54 may be ordered from the Middle American Research Institute, Tulane University, New Orleans, Louisiana 70118 USA.

—H.C.S.

REVIEW OF *POSTLIGATA*, A LATE CRETACEOUS PELECYPOD

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ABSTRACT

The late Cretaceous pelecypod *Postligata* is shown to be glycymeridid with opisthogyrate beaks, and in extreme instances, a prosodetic ligament. It lacks radial ribs or striae. *Postligata* has been reported from Georges Bank southwestward to Mississippi and Tennessee.

The name *Postligata* was used by Gardner (1916, p. 543) as a proposed subgenus of *Glycymeris*. She assumed that the ligament was behind the beaks (opisthodetic), hence the name *Postligata*. She also assumed that the beaks pointed forward (prosogyrate). Gardner's two assumptions for the orientation of the shell of *Postligata* are what one would expect for most pelecypods. However, if we assume that *Postligata* is a glycymeridid as Gardner thought, it would be appropriate to compare this genus with other living and fossil glycymeridids. Newell (1969, p. N269) and most other paleontologists have oriented *Postligata* and other glycymeridids incorrectly, but malacologists (Abbott, 1974, p. 426) have oriented the shells of glycymeridids correctly, and this is based on both anatomical and shell characteristics.

The following morphological features of the shell are helpful in the orientation of the valves of glycymeridids (Nicol, 1947):

1. The scar of the anterior adductor muscle is subtrigonal, with the dorsal side more angular than the corresponding side of the posterior adductor muscle scar, which is subcircular.

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2. If the adductor muscle scars are unequal in size, the larger one is the anterior.

3. Where the pallial line joins the adductor muscle scars, small sinuses are formed. The deeper sinus is below the posterior adductor scar.

4. The flange bordering the anterior side of the posterior adductor scar is more abrupt or steep than the flange bordering the posterior side of the anterior adductor scar.

5. In somewhat oblique shells, the axis slopes downward posteriorly. In shells that have one end either truncated or produced, it is the posterior end.

6. On the exterior of the shell, the posterior end bears more borings and various attached organisms.

7. In Recent specimens, the interior of the shell is more highly colored on the posterior side.

If the beaks are not orthogyrate, they are always opisthogyrate in all living species of glycymeridids. Opisthogyrate beaks are not nearly so common as orthogyrate beaks, but opisthogyrate beaks occur in *Axinactis*, *Glycymerella*, most species of *Axinola*, some species of *Glycymeris*, and a few species of *Tucetona*. The earliest species of glycymeridids all had orthogyrate beaks, but before the end of the Cretaceous some species developed opisthogyrate beaks. However, in the Cenozoic the trend has been for a greater frequency of opisthogyrate beaks. Thus, the ligament is: exactly amphidetic, amphidetic but placed more in front of the beaks than behind them; or, in some in-

stances, completely in front of the beaks (prosodetic). If the chevron-shaped grooves of the ligament are unequal, the anterior limb is always longer than the posterior limb, and in a few extreme instances, the posterior limb is absent. We have figured (Figure 1) Wade's species of *P. crenata* to show the proper orientation of *Postligata*. Opisthogyrate beaks occur in some other arcoids such as the Noetiidae, but some species of anadarids have strongly prosogyrate beaks.

There are at least six described species of *Postligata*, of which the type, *Glycymeris wordeni* Gardner, is one of the most aberrant. The evolutionary trends include a circular outline and a small size. Some species attain a height and length of less than 10.0 mm. They are lenticular and the ratio of height to convexity (the distance between the two valves) is generally 0.50 or slightly less, which is very low for most glycymeridids. The interior ventral margin has no crenulation in *G. wordeni* Gardner, 1916. This lack of crenulations also occurs in *Postligata aventi* Stephenson, 1947, and *P. monroei* Stephenson, 1947. Small crenulations do occur in *P. crenata* Wade, 1926, and *G.* (?) *greenensis* Stephenson, 1923. The interior ventral margin was not exposed in Stephenson's species *P. schalki*, 1936. The outer surface of the shell has only concentric lines and radial ornamentation is lacking in all six species of *Postligata*. The lack of radial ornamentation is rare in glycymeridids, but at least one living species of *Axinola* does not have radial ribs.

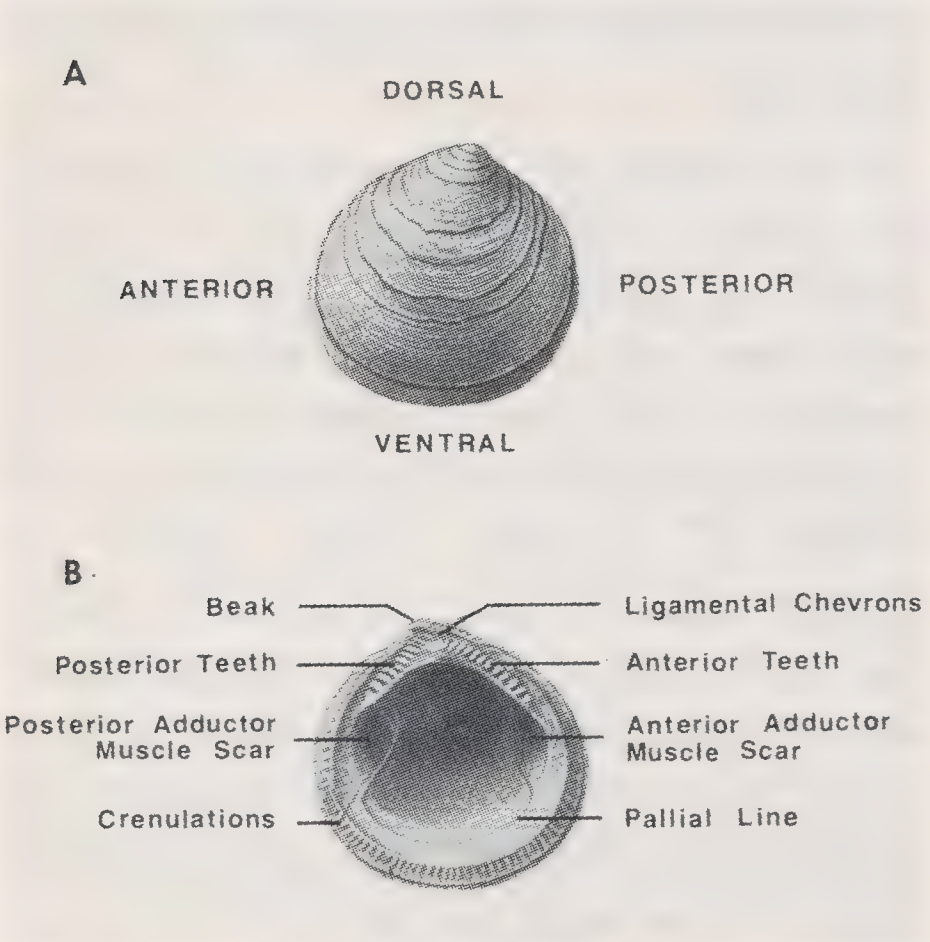

Figure 1. *Postligata crenata* Wade, 1926, showing the proper orientation of the shell. Height and length of specimen 9.0 mm. A, Exterior view. B, Interior view.

Glycymeris subgyrata Stephenson, 1927, can possibly be allocated to *Postligata*. It lacks radial ribs but the interior ventral margin is crenulate, the beaks are only faintly opisthogyrate, and the height and length of the valves are about 30.0 mm. Another species which also may be allocated to *Postligata* is *Glycimeris [sic] subcrenata* Wade, 1926. In this species the beaks are apparently orthogyrate; there are faint radial striae on the outer surface of the shell, but the inner ventral margin is almost smooth. The ratio of height to convexity in *Glycymeris subcrenata* is low and the valve outline is typically circular. When all the species of *Postligata* are examined, it becomes obvious that there are clear morphological characteristics that link a typical glycymeridid to *Postligata* and that this genus was an aberrant and short-lived member of the Glycymerididae during the late Cretaceous.

The known geographic range of the six species of *Postligata* is from Georges Bank southwestward to Tennessee and Mississippi. The genus has been reported from Delaware, Maryland, North Carolina, and South Carolina (Figure 2). The stratigraphic range of the genus is Maastrichtian and possibly Campanian.

Newell (1969, p. N268) erected a new subfamily of glycymeridids, the Arcullaeinae, for the genera *Arcullaea, Peruarca, Pettersia, Postligata, Protarca,* and *Trigonarca*. These Cretaceous genera have hinge teeth and a ligament that resemble the Glycymerididae. Except for *Postligata,* there is no direct evidence that the other five genera arose from a glycymeridid ancestor or that they are closely related to each other. Some of these genera are monotypic and are known from few specimens. Apparently several stocks, which had cucullaeoid-type teeth, developed acroid-type teeth through neotony during the Jurassic and Cretace-

ous (Nicol, 1950, p. 96). In other words, the Arcullaeinae is a polyphyletic taxon. The exact family relationships of all of these genera, except *Postligata*, are unknown at the present time and should be considered as *incertae sedis*.

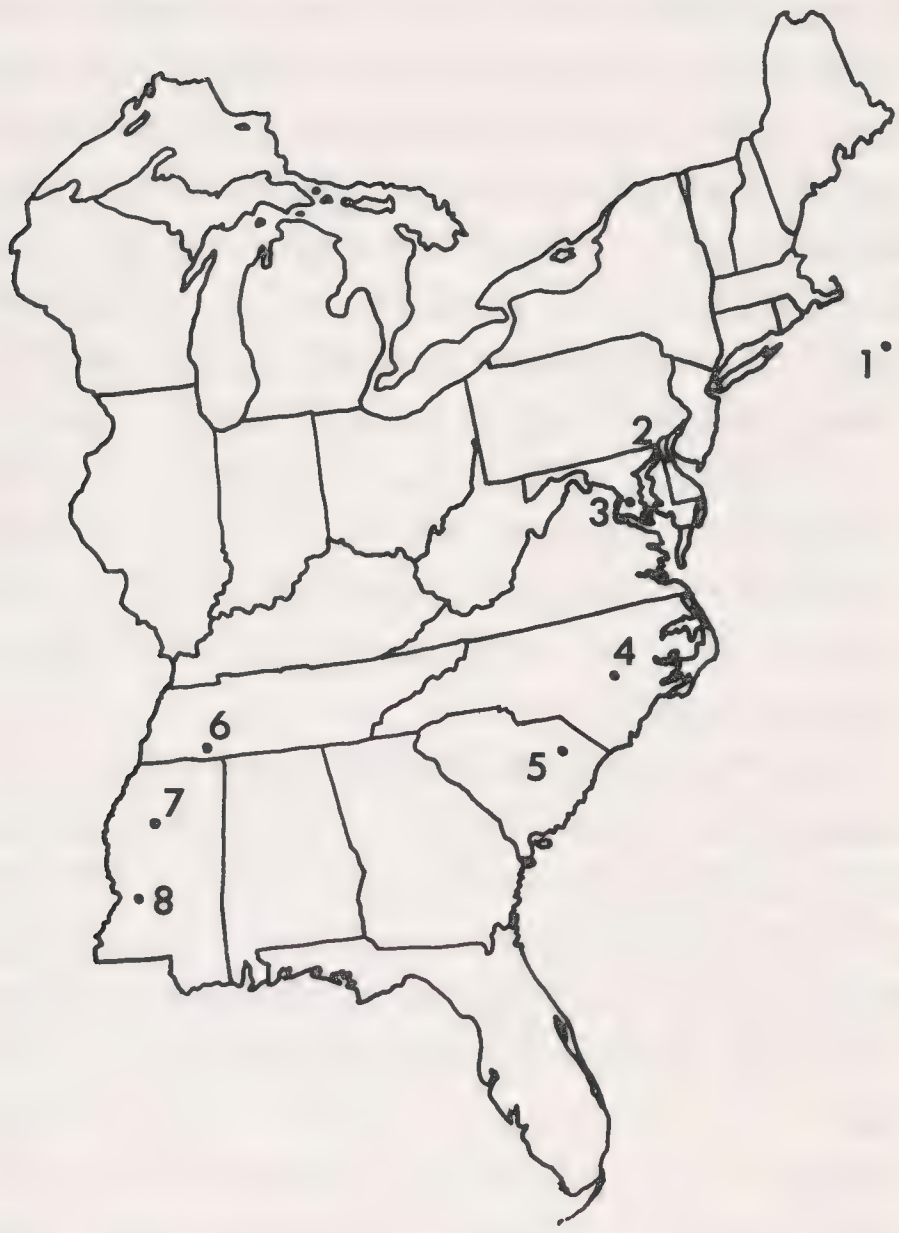

Figure 2. Map showing the known geographic range of *Postligata*. 1. Georges Bank; Stephenson, 1936. 2. Delaware; Richards and Shapiro, 1963. 3. Maryland; Gardner, 1916. 4. North Carolina; Stephenson, 1923. 5. South Carolina; Stephenson, 1927. 6. Tennessee; Wade, 1926. 7. Mississippi (subsurface); Stephenson, 1947. 8. Mississippi (subsurface); Stephenson, 1947.

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CHANGES IN THE HINGE TEETH OF ARCACEANS FROM DEVONIAN TO RECENT

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ABSTRACT

The arcaceans first appeared during the middle Devonian Givetian Stage. Major diversification of this superfamily began in the Jurassic and has continued throughout the Cretaceous and Cenozoic. The hinge teeth have decreased in size and increased in number from Devonian to Recent.

The first pelecypods that appear to be true arcaceans occur in the middle Devonian Givetian Stage. Although many paleontologists have said that the cyrtodonts were the ancestors of the arcaceans, I agree with Morris (1967, p. 474), who said that this is not firmly established.

The type of hinge teeth possessed by arcaceans can be placed in three categories. The first group includes species with elongate teeth on either the posterior end or at both posterior and anterior ends of the dorsal border, which are parallel or nearly parallel to the dorsal border (Fig. 1a). These may be referred to as cucullaeid-type teeth. The side teeth may be long and few in elongate shells and shorter and more numerous in shells that are nearly as high as they are long. The second includes species with thick shells and very large side teeth that slope away from the dorsal border, which may be referred to as pseudocucullaeid-type teeth (Fig. 1b). Pseudocucullaeid-type teeth occur in shells that are squarish or rounded in outline. The third includes species with numerous small teeth throughout the hinge plate. These are true arcid-type teeth (Fig. 1c). Cucullaeid-type teeth undoubtedly gave rise to both pseudocucullaeid- and arcid-type teeth. Table 1 shows the ranges of genera and subgenera with these three types of teeth (data taken from Newell, 1969, p. N250-N269, and from many faunal monographs on fossil pelecypods).

The Paleozoic arcaceans have some variability in valve outline, ornamentation, and position of the beaks. The valve outline is commonly rectangular, resembling *Arca,* but a few species are almost as high as long and resemble *Cucullaea.* The beaks are commonly located toward the anterior end; in a few instances the beaks are located at or near the anterior end, giving the shell a mytiloid outline. Ornamentation may be lacking or may consist of concentric or radial ribs. There are always elongate posterior side teeth parallel to the

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Table 1. Geologic distribution of genera and subgenera of arcaceans with cucullaeid-type teeth (C), pseudocucullaeid-type teeth (P), and arcid-type teeth (A).

Geologic Period	No. of Genera and Subgenera C	P	A
Neogene	2		48
Paleogene	3		29
Cretaceous	7	3	20
Jurassic	7		3
Triassic	3		1
Permian	1		
Pennsylvanian	2		
Mississippian	1		
Devonian	1		

dorsal margin, and sometimes there are also elongate anterior side teeth (Fig. 1a). Most Paleozoic arcaceans have been allocated to *Parallelodon* or *Grammatodon* and all of them appear to have been byssally attached to the substrate.

The Triassic arcaceans show little more variations than their Paleozoic ancestors (Table 1), but beginning in the Jurassic some stocks have a reduction of the size of the teeth and an increase in their number, resembling modern *Anadara, Noetia,* and *Glycymeris*. However, stocks having hinge teeth like *Parallelodon* and *Cucullaea* also proliferate in the Jurassic. The radiation of the arcaceans increases greatly in the Cretaceous. With the rise of the glycymeridids (Nicol, 1950a, p. 97), the limopsids (Oliver, 1981, p. 71), the Noetiinae (Newell, 1969, p. N261), and the Striarcinae (Newell, 1969, p. N263), there was a great increase in the number of genera and species of arcaceans having smaller teeth. Some short-lived stocks, such as *Arcullaea, Peruarca, Pettersia, Protarca,* and *Trigonarca,* also have a reduction in the size of the side teeth during the Cretaceous, and the hinge teeth of these groups of Cretaceous arcaceans take on a modern appearance. All of these aforementioned groups have a squarish or rounded outline. However, the cucullaeid-type of hinge teeth were still common, as is seen in such genera as *Idonearca* and *Nemodon*. There was an extreme development of the side teeth in three short-lived Cretaceous genera: *Dicranodonta, Lopatinia,* and *Pseudocullaea* (Fig. 1b). *Pseudocucullaea,* in particular, had a large thick shell and many side teeth that sloped away from the dorsal margin towards the ventral margin. This genus had a geographic distribution that included West Africa, northern South America, and the Caribbean. None of these three genera with greatly developed side teeth survived the Cretaceous Period. The arcaceans suffered a considerable amount of extinction near the end of the Cretaceous, when no less than 15 genera and subgenera disappeared. The casualties included arcaceans with large side teeth and those with small numerous teeth. Most of the genera and subgenera that became extinct at the end of the Cretaceous were short lived, but a few had geologic ranges that included Jurassic and older geologic periods.

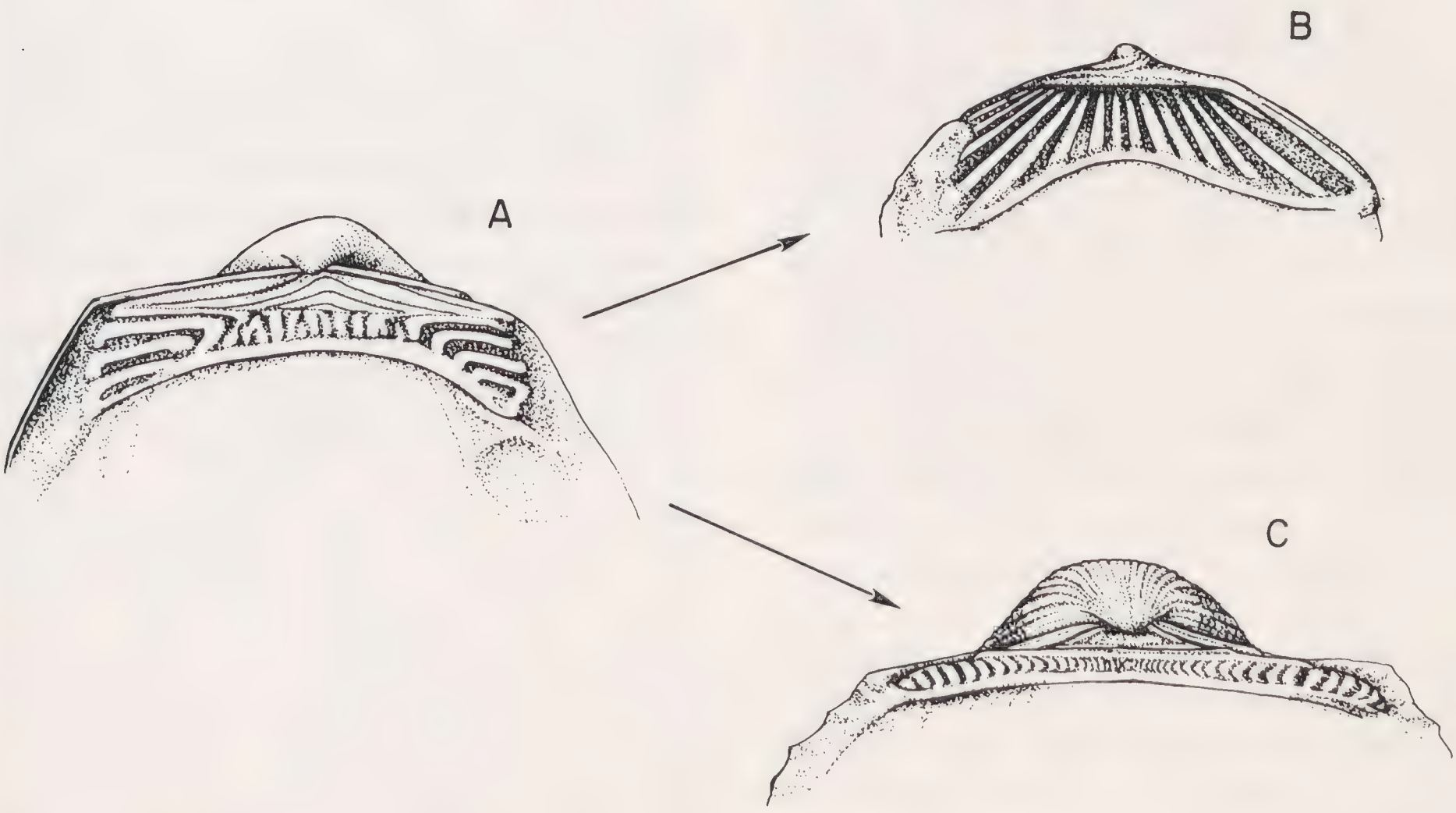

Figure 1. The three types of hinge teeth seen in fossil and living arcaceans: A, cucullaeid; B, pseudocucullaeid; C, arcid.

The genera of arcaceans with elongate side teeth in the Cenozoic are few in number, and these genera have few species. The living species of *Cucullaea,* which is an Indo-Pacific relict, has the side teeth and the hinge plate reduced in size (Nicol, 1950b, p. 339). However, Paleogene and Cretaceous cucullaeids have much larger side teeth and a massive hinge plate. The ventral border of living *Cucullaea* has fine crenulations, and many species of fossil cucullaeids had well developed denticulate margins. In living *Arca* the hinge teeth are reduced to fine crenulations. The most extreme example of reduction of hinge teeth is seen in the glycymeridid genus *Grandaxinaea.* This genus, which is confined to Australia and New Zealand, lacks teeth in large specimens (Nicol, 1950a, pl. 20, fig. 8), but the ligamental area is unusually high and large.

The question arises why the arcaceans have reduced the size of the teeth and increased their number from the inception of this superfamily in the Middle Devonian to the Recent. Thomas (1978, p. 335) has noted that the arcaceans do not have a strong ligament. A few large teeth would seem to be a more effective locking device than many small teeth, and it would seem that a strong locking device for the valves would have an adaptive advantage. This reduction of the size of the teeth occurs in both byssate and shallow-burrowing species, and it also occurs in elongate as well as square or rounded shells. Most byssate species lack crenulations on the ventral margin and most burrowing forms have them, but there are many exceptions. It is not apparent that crenulations on the ventral border replaced the large hinge teeth seen in Paleozoic and Mesozoic arcaceans. Another possible device for keeping the valves of some arcaceans in alignment is that the left valve overlaps the right valve along the ventral margin, as is seen in some cucullaeids and anadarines (Nicol, 1958, p. 62). The inequivalve condition is sometimes accompanied by different ornamentation on the two valves. Anadarines with inequivalved shells tend to have squarish outlines and comparatively thin shells. Perhaps the ligament has become larger and more efficient in most Cretaceous and Cenozoic species, and this structure has helped to keep the valves in proper alignment.

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CHIONE (CHIONE) CRASPEDONIA DALL IN THE CRYSTAL RIVER FORMATION (EOCENE) IN PENINSULAR FLORIDA

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The youngest beds of the Crystal River Formation in peninsular Florida are generally considered to be late Eocene in age. The presence of the following genera and subgenera: *Asterocyclina, Hantkenina, Cribrogloborotalia, Pseudophragmina (Proporocyclina),* among the foraminiferids; the annelid worm *Rotularia;* the echinoid genera *Wythella, Weisbordella, Eurhodia, Phymosoma;* clearly indicate an Eocene age for these strata (Nicol, *et al.*, 1976, p. 143). The beds are referred the *Rotularia vernoni* zone (Nicol and Jones, 1982) and are equivalent to Puri's *Asterocyclina-Spirolaea* [sic] *vernoni* faunizone. It has been suggested by Druid Wilson (personal communication) that these beds may be reworked Oligocene strata; however, in the vicinity of Gainesville, Florida, there is no indication that the beds have been reworked. Isolated silicified boulders of Suwannee Limestone represent the only Oligocene material near Gainesville, and the sole Oligocene fossil that has withstood long erosion and reworking is the robust irregular echinoid *Rhyncholampas gouldii* (Williams, *et al.*, 1977).

Chione (Chione) craspedonia Dall, 1903, is a species that is abundant in rocks of Oligocene age in the Gulf Coast, but it is also the most common pelecypod in the *Rotularia vernoni* zone and occurs sparsely in the *Nummulites vanderstoki-Hemicythere* faunizone. Although Palmer (1927, 1929) does not report the genus *Chione* from Eocene beds in the eastern United States, it now appears that this genus is present in beds of late Eocene age in peninsular Florida. The molluscan fauna of the *Rotularia vernoni* zone in the Crystal River Formation has been virtually unstudied.

At least two other stocks of pelecypods that first appear in the *Rotularia vernoni* zone in peninsular Florida are well represented in Oligocene strata in the United States. One of these is a species that has tentatively been identified as *Chlamys (Lyropecten) incertae* Tucker-Rowland, which can be allocated to the subgenus *Anatipopecten*. This subgenus was also reported from the lower bed near Bainbridge, Georgia. The second is a distinctive split-ribbed species of *Glycymeris* that closely resembles *Glycymeris intercostata* (Gabb) and *Glycymeris cookei* Dall. The latter species was also reported by Dall (1916) from the lower bed at Bainbridge, Georgia, and it is likely that this lower bed is partly equivalent to the *Rotularia vernoni* zone in peninsular Florida. This group of split-ribbed glycymeridids consists of about ten species, is confined to the tropical western hemisphere, and ranges from late Eocene to Recent. The sole living species is *Glycymeris multicostata* (Sowerby), which is confined to the tropical eastern Pacific.

Beginning with Puri's *Nummulites vanderstoki-Hemicythere* faunizone, which is immediately below the *Rotularia vernoni* zone, invertebrate stocks with Oligocene affinities begin to appear in peninsular Florida, and the stocks with Tethyan affinities nearly disappear (Cheetham, 1963; Nicol, *et al.*, 1976; Jones, 1982). In the *Rotularia vernoni* zone the stocks with Tethyan affinities have disappeared, and the character of the invertebrate fauna becomes much more provincial.

The span of time between the latest Eocene in peninsular Florida, which is represented by the *Rotularia vernoni* zone, and the Red Bluff, Forest Hill, and

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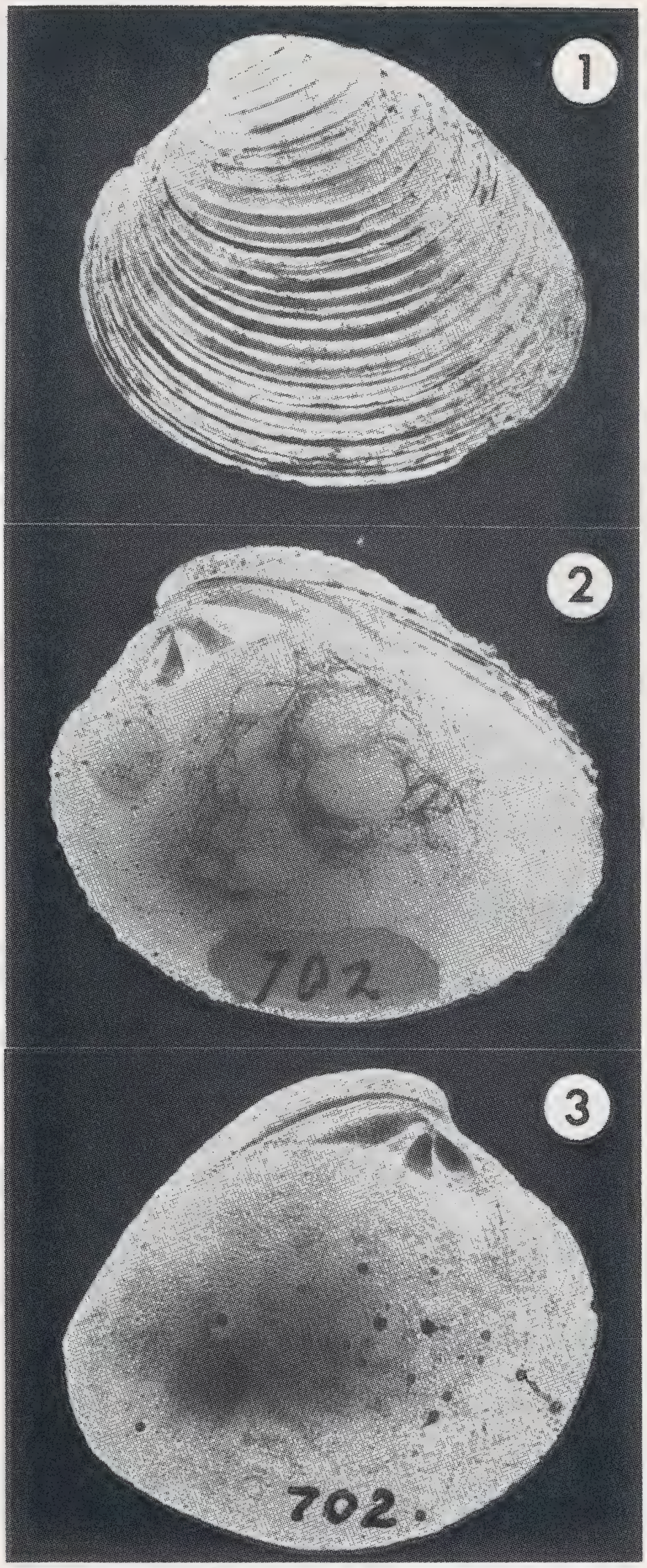
Mint Spring formations of the lower part of the Vicksburg Group in Mississippi probably represents no more than four million years and possibly no more than two or three million years (A. Palmer, 1983, p. 504). It is not surprising, then, that some molluscan species in the *Rotularia vernoni* zone of the Crystal River Formation are very similar or identical to those in older beds of the Vicksburg Group in Mississippi.

The specimens studied for this paper consist of about 200 siliceous pseudomorphs that come from one locality near Gainesville, Florida, in the *Rotularia vernoni* zone, and three of the best specimens are figured herein. The locality is in the Gainesville West Quadrangle in a shallow quarry 0.5 mile south of the intersection of State Road 26 and I-75, west of Gainesville, Alachua County, Florida (SW ¼Sec. 4, T10S, R19E). Most of the specimens are so poorly preserved that only a generic identification could be made. Some of the valves have been bored by gastropods. *Chione (Chione) craspedonia* does occur, however, at many other localities in peninsular Florida as casts and molds in limestone.

The specimens we have of *Chione (Chione) craspedonia* are the same size and shape as the specimens measured and figured by Dockery (1982, p. 94, pl. 48, figs. 4-9, text figs. 47, 3-4). They are also like Dall's (1903, p. 1300, pl. 55, fig. 2) original description of this species. The concentric ribs are more widely spaced on small specimens and on the umbonal region of adult forms. There is no indication of radial ribs on any of our specimens. The interior ventral margin is finely crenulated, and fine crenulations also occur on the anterior dorsal border above and anterior to the cardinal teeth. The lunule is set off by a furrow that runs from the beak to the dorsal margin. The furrow becomes wider toward the dorsal margin, but the lunule inside the furrow is not sunken.

Chione (Chione) craspedonia can be readily separated from *Chione (Chione) bainbridgensis* Dall, 1916, by the lack of ra-



Figures 1-3. *Chione (Chione) craspedonia* Dall. (All specimens in the Invertebrate Paleontology collection at the Florida State Museum.) 1. Exterior, right valve (hypotype-cat. No. 5702); length 21.8 mm, height 19.0 mm. 2. Interior, right valve (hypotype-cat. No. 5701); length 27 mm, height 23.2 mm. 3. Interior, left valve (hypotype-cat. No. 5703); length 22.6 mm, height 20.4 mm.

dial ribs on the former species. Dockery (1982, p. 94, 96) has explained how to differentiate *Chione (Chione) craspedonia* from two other similar species, *Chione (Chione) perbrevisformis* Dockery and *Chamelea mississippiensis* (Conrad).

ACKNOWLEDGMENTS

We are particularly indebted to Dr. David T. Dockery, III, of the Mississippi Bureau of Geology who supplied copies of his work on the Vicksburg Bivalvia. At the Academy of Natural Sciences of Philadelphia, Dr. George Davis and Mr. Gary Rosenberg helped Dr. Jones locate specimens of *Chione*. At the National Museum of Natural History, Mr. Druid Wilson and Dr. Thomas Waller helped Dr. Jones locate type specimens of *Chione* in the Invertebrate Paleontology collection.

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October 31, 1984

REVIEW

IT BEGAN WITH A STONE: a History of Geology from the Stone Age to the age of Plate Tectonics, by Henry Faul and Carol Faul. Published by John Wiley & Sons, New York, Chichester, Brisbane, Toronto, and Singapore, 1983, xvii + 270 pp., 51 figs., $38.95

Henry Faul died as his book neared completion; Carol finished the task Henry had begun. Thus, this volume represents Henry's final comments on the history of geological thought. He collected early geological books with great dedication. This led him to write on the history of geol-

ogy and to begin lecturing on this subject at the University of Pennsylvania and elsewhere including Shiraz, Iran, where he and Carol taught during a sabbatical leave in 1974, and where the writing of this book was begun.

It is exceedingly difficult to trace the development of geological thought chronologically through the centuries. This is particularly so after 1450 due to several factors including the near-exponential increase in the number of authors who recorded their geological observations in printed books and the progressive separation of natural philosophy into the several sciences and the development of subdisciplines within each of the major subdivisions of science. The development of geological thought and the ultimate "birth" of geology as a separate discipline is intimately related to each of the sciences and their subdivisions. The authors of *It Began with a Stone* address this difficulty with a more-or-less geographical organization of their narrative after an overly brief chapter on *Antiquity* followed by an even briefer one on *The Middle Ages*.

Thus, the third chapter is headed *Geology was Born in Italy*. This reviewer is forced to disagree with this statement just as he would with *Geology was Born in Greece* if such had been their choice. Recognizing that the argument is largely semantic; that is, dependent upon what one defines as "geology" in order to trace its "birth," it is felt that the case for Italy as the "birthplace" of geology is weak. Observations recorded in Leonardo da Vinci's notebooks were brilliant to be sure but their importance remained unrecognized until much later. The only scientist who contributed clear and coherent geological observations at an early date was Niels Stensen, a Dane attached to the Medici Court in Florence (now Italy) as court physician. During the several years he resided in Florence, Stensen formulated three fundamental principles of historical geology. However, the first of his two major geological works, *Canis Carchariae Dissectum Caput* (1667), was appended to his treatise on musculature, and the second, *De Solido Intra Solidum Naturaliter Contento Dissertationis Prodromus* (1669), as the title implies is a long summary of the full treatise he later planned to write. Thus, it was a full century later that a new science, geology, emerged to be recognized as a separate activity and discipline. Aside from the work of Stensen which has been given full and proper attention by previous historians of geology, contributions from observers in Tuscany and other city states within what is now known as Italy have been somewhat underemphasised, but overstatement of their importance should be avoided.

Succeeding chapters include *The French Connection, The Detour Via Freiburg, The Quiet in Britain, Geology Comes of Age in Britain, The French Reaction, Provincial Beginnings in America,* several chapters on the state and western surveys and expeditions, and *The Physico-chemical View.* The concluding chapters are *Cooling Earth, Flexing Continents, Radioactivity;* and, *Continental Drift, Subsiding Ocean Basins, Things to Come.* The contributions of the French and German schools are reviewed, followed by consideration of the British geologists. The role of the latter is somewhat understated except for the contributions of Sir Charles Lyell. The development of geology in America is elucidated far beyond that of most previous authors. The final chapters are a brief, tantalizing glimpse of the importance of Continental Drift and Plate Tectonics to geological thought. Considering Henry Faul's expertise in geophysics, this reviewer had hoped for more on these absorbing topics.

This is a good, useful, readable book. We can be gratified that Henry's lectures on history of geology have been preserved. There is much to be learned from them, and the fresh insight into the work of past geological observers is worthwhile. The more than 550 references are exceedingly useful though the citations are distressingly brief in places. Perhaps this could not be avoided. This volume is recommended for both the historian and the working geologist.

—H.C.S.

LYELL'S PROPOSAL OF THE TERM "PLEISTOCENE"

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In order to simplify his terminology of Tertiary subdivisions, and probably at the urging of his friend, Charles Darwin, Charles Lyell introduced the Pleistocene "period" (Wilson, 1972, p. 484-485). The term was substituted for "Newer Pliocene" as the name of the most recent of the Tertiary divisions, based on the ratio of extant to extinct species of fossil mollusks. According to Lyell's original criteria, the presence of ninety percent or more extant species from any formation anywhere in the world indicated deposition during the Newer Pliocene (Lyell, 1833, p. 58-59). (Lyell's concept of percentages recently has undergone a very interesting revival at the hands of evolutionary paleobiologists; see Stanley, 1979, p. 113-118.). Because attributes of assemblages of fossil mollusks were the first keys to the identification of latest Tertiary formations, we reproduce in Figure 1 Lyell's illustration of the species regarded as typical Pliocene forms.

The initial division of the Pliocene period into Newer and Older seems to have resulted from Lyell's working relationship with Gerard Deshayes, who he referred to as "the first fossil conchologist in Europe" (from letter to Gideon Mantell, 10 October 1830 *in* Lyell, 1881, p. 306-307). Deshayes believed that the Tertiary was divisible on paleoconchologic grounds into only three major subunits — the Pliocene, Miocene, and Eocene periods, as subsequently designated by Lyell (1833; see also Berry, 1968, p. 106).

Lyell became fully aware of the need for a fourth subdivision during his exploration of southern Italy and Sicily in 1828. His growing awareness of the richness of the stratigraphic record of the latest Tertiary is recorded in his personal correspondence:

> I found Ischia just what I had hoped, a most admirable illustration of Mont Dore, with the difference which we sometimes wished for, as the substitution of marine for freshwater, and the consequent abundance of organic remains . . . I have now the satisfaction of having an example of marine remains at a greater height than any of Brocchi's sub-Apennines, and belonging to a formation decidedly more recent. (from letter to Roderick Murchison, 6 November 1828 *in* Lyell, 1881, p. 210-212)

His growing conviction that the Pliocene should be separated into Older and Newer divisions was reinforced during the tour of Sicily:

> . . . What will you say if I tell you that even the blue marl with its capping of yellow sand cannot be Brocchi's sub-Appenine beds? I am come most unwillingly to this conclusion. But the numerous extinct species which characterised the sub-Appenines are wanting here, and living shells are present too plentifully to admit a doubt that it is more related to our own epoch that that remote one when the Parmegiano and Placentino beds were deposited. (from letter to R. I. Murchison, 12 January 1829 *in* Lyell, 1881, p. 232-234).

Thus, it was in southern Italy that Lyell found the compelling reasons to subdivide the Pliocene; here he found evidence for a Tertiary period younger than the period in which the Subapennine beds of the Italian peninsula were deposited. But because of his reliance on Deshayes' compilation of paleoconchologic data (Lyell, 1833, Appendix I), Lyell did not employ a fourth distinct "period" for these very young, fossiliferous deposits when he wrote

the third volume of the *Principles*. Lyell regarded the deposits of the Val di Noto in Sicily, and on the island of Ischia, just offshore from Naples, as typical Newer Pliocene formations (Lyell, 1833, pp. xii-xiii, 54, 63-66, 126-127; see also Wilson, 1972, map 9).

Later, Lyell found that the Pliocene could be subdivided even further as work proceeded on the Crag and other later Tertiary deposits, and on their contained fossils (Wilson, personal communication, 1981). Wilson (1972, p. 485) has written:

> As the number of subdivisions of the Pleiocene period had increased, he (Lyell) had found himself in the uncomfortable position of referring to the upper and lower 'older Pleiocene' and the arkwardness of this suggested the need for new terms.

The term "Pleistocene," then, was finally substituted for Newer Pliocene as a kind of utilitarian afterthought in an Appendix to the first edition of the French translation of the *Elements of Geology* (Lyell, 1839). This curious supplement to the main text reads like the "notes added in proof" of modern publications, and served to update the Tertiary divisions then in use. Because of the obscure location of the original proposal of the term, few students of the Pleistocene have actually read the passages containing the designation of the new division. Surprisingly, the geologists of our acquaintance whom we questioned about its origin were only vaguely aware that Lyell had actually proposed the term and the majority had no idea when or where the term first appeared. For these reasons, and to provide additional available documentation of the evolution of Lyell's Tertiary subdivisions, we present a translation of the Appendix to the French *Elements* , followed by the original text (Lyell, 1839, p. 616-621). We have added footnotes to the translation to identify colleagues and publications to which Lyell refers.

In the third chapter of this work,[1] I said that important additions were made to collections of living and tertiary fossil shells, during the past ten years, making necessary the revision of that part of the classification of tertiary formations which rests principally upon the relative proportion of recent to fossil species in each group.

Since the publication of the previously mentioned chapter in the English edition,[2] I have been earnestly researching this subject; and already these researches have led me to the modification and amplification of some of my initial ideas, — changes which I am going to give in this appendix, in a manner as abbreviated as possible.

After recent investigations, it appears that the English Crag, which I reported as entirely Older Pliocene (See p. 349), belongs to several periods, namely: the Red Crag and the Coralline Crag of Suffolk, the fossils of which are shown on pages 353-356, are characteristic of the Miocene epoch; and only the Norwich Crag is entirely Older Pliocene. The following considerations caused the change of opinion.

1. The beds of shelly sand and clay which are known as Crag, and which, in the county of Norfolk, overlie a chalk, representing fluvio-marine deposition, contain 90 species of marine shells, and about 20 species of freshwater and terrestrial shells. Among these shells, the number of recent species is, as for the present, around 50 to 60 percent. This formation can be placed in the oldest Pliocene period, in which at one time I placed all of the English Crag.

2. The number of fossil shells from the Red Crag of Suffolk excluding the annelids and cirripeds, is 214 in the collection of Mr. Searles Wood.[3] of this number, 64 are recent species, which establishes, with regard to extinct species, a proportion of about 30 percent.

3. In the same collection, of 329 shells collected from the Corallline Crag, there are 62 recent species, that is 19 percent.

I was assisted in this comparison of fossil and recent shells by two very distinguished naturalists Mr. Searles Wood, who possesses a profound knowledge of British tertiary shells; and Mr. G. -B. Sowerby,[4] whose knowldege of recent shells is justly appreciated by all conchologists.

The predominance of the above mentioned extinct species in the Red Crag and in the Coralline Crag indicates a great differ-

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Figure 1. Reproduction of Plate 1 from *Principles of Geology* (1833), Volume III, showing fossil shells regarded by Lyell as typical Pliocene forms. Numbers 1, 7, 9, 11, 13, and 14 were listed by Lyell as being found in Newer Pliocene, or Pleistocene, deposits; no attempt has been made to update the fossil names.

1. 2. Turbo rugosus. Lin. _ 3. 4. Trochus magus. Lin. _ 5. Solarium variegatum. Lam.k 6. Tornatella fasciata. Lam.k _ 7. Pleurotoma vulpecula. Broc _ 8. Fusus crispus. Bors 9. Buccinum prismaticum. Bors _ 10. Pleurotoma rotata. Broc _ 11. Buccinum semistriatum. Broc _ 12. Mitra plicatula. Broc _ 13. Cassidaria echinophora. Lam.k _ 14. Cytherea exoleta. Lam.k var.

ence between the fauna of the neighboring sea and that of the two formations, which I was inclined to attribute to different epochs of the Miocene period. This difference, in regard to the living fauna of the German Ocean,[5] is not confined to species; it also extends to many genera which, actually, are foreign to the adjacent seas: such as, among others, a large Cassis, and a Voluta in the Red Crag; a Pyrula, a Voluta, a Lingula, a Pholadomya, and a Glyximeris [*sic*] in the Coralline Crag. Many corals (stone-corals) are found in the latter deposits, the species of which belong to the intertropical genus Anthophyllum.

After carefully examining, in 1825, the Suffolk Crag and the faluns of Touraine, M. Desnoyers[6] decided, in his opinion, that the two formations were contemporaneous.[7] This conclusion, which I consider today to be very probable, was, in principle, contested by me with regard to the supposedly large proportion of recent shells in the Suffolk Crag, and the distinction that exists between the species of fossil shells from Touraine and those from Norfolk and from Suffolk.[8] The first of these arguments was based on an error, that resulted pirincipally from the more recent shells of the Norfolk Crag being confused with those of the Suffolk, and attributed to the same period, — a circumstance which gave a greater proportion of recent shells than that which is fitting for the Red Crag or for the Coralline Crag of Suffolk, if each were taken separately. The other argument, namely, the distinction between fossil species from Suffolk and those from Touraine, presents a great difficutly, since out of one hundred species, there are not ten which are common to the two formations.

After examining, jointly with Mr. G. -B. Sowerby, a collection of 236 species of shells from Touraine, assembled by M. Dujardin,[9] and described by him in the Mémoires de la Société géologique de France (See this work, vol. II, page 211),[10] we have found, among these shells, a proportion of 26 percent of recent species. As for fossil species, those from the Suffolk Crag are for the most part identical to those from British regions and arctic climates, likewise, here, they resemble Mediterranean or North African species. One could say that during the time of deposition of the two formations in question, a geographic barrier extended across the English Channel, separating it into two gulfs, one opening to the north and the other to the south.

Mr. Sowerby also examined with me 400 species of shells from Eocene marine and freshwater formations of England. In their number, we found only four which could be identified as recent species. This proportion of 1 percent could perhaps be raised slightly; but we believe that in each case this augmentation would not be considerable, because the collections of living shells which, in the course of our research, we have examined, are part of the richest which exist in Europe.

On the other hand, some of the most recent shelly deposits in England, as much lacustrine as marine, contain more than 90 or 95 percent living species; and I doubt that everything that is to be discovered has been discovered including, in the different tertiary deposits of Europe, almost all proportions intermediate between those which characterize the English Eocene mentioned above, in which scarcely one percent of recent species is found; and the opposite case, in which the same proportion of extinct species is found. Already, finding that it will become necessary to establish an arbitrary line of demarcation between those deposits to which I have given the names of Older and Newer Pliocene,[11] I designated the former, that is to say the most ancient of these groups, the strata which contain 40 to 70 percent recent species of shells; and the most modern, those in which this proportion exceeds 70 percent.

However, at the same time that it became necessary to subdivide the two periods mentioned here, I found that the terms destined to designate those subdivisions were inconveniently long, and I propose to employ in the future the word Pliocene for the Older Pliocene, and to substitute for the designation Newer Pliocene the abbreviation of *Pleistocene*, taken from the Greek pleiston, *most*, and kainos, *recent*.

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1. 1839, *Elements of Geology* (first French edition)
2. 1838, *Elements of Geology* (first English edition)
3. Searles Valentine Wood (1798-1880). English paleontologist and Tertiary mollusk authority; specialized in Crag fossils of Suffolk and Norfolk, and Eocene fossils of the Hampshire Basin (*see* Lambrecht *et al.*, 1978, p. 466).
4. George Brettingham Sowerby (1788-1854). English Conchologist and paleontologist; member of famous family of naturalists that included James Sowerby (father) and James De Carle Sowerby (older brother) (*see* Lambrecht *et al.*,1978, p. 406).

5. North Sea.
6. Jules Pierre Francois Stanislas Desnoyers (1800-1887). French geologist and archaeologist; one of the founders of the Société Géologique de France, Librarian of the Muséum d'Histoire Naturelle, and author of memoirs on the Mesozoic and Cenozoic deposits of the Paris Basin and Northern France (*see* Lambrecht *et al.*, 1978, p. 114),
7. *see* Desnoyers, 1825, Mémoire sur la craie, et sur les terrains tertiaires de Contentin:Mém. Soc. d'Hist.Nat. de Paris, v. 2, p. 176-248.
8. *see* Lyell, 1838-39, Lettre à M. Desnoyers sur le crag du Norfolk et du Suffolk: Soc. Géol. Bull., v. 10, p. 321-322.
   see also Lyell, 1839, On the relative ages of the tertiary deposits commonly called Crag, in Norfolk and Suffolk: London and Edinburgh Philosophical Magazine and Journal of Science, series 3, v. 15, p. 407-411.
9. Félix Dujardin (1801-1862). French zoologist and geologist; professor of mineralogy and geology in the Faculté des sciences de Toulouse, and later professor of zoology in the Faculté des sciences de Rennes (*see* Lambrecht *et al.*, 1978, p. 121).
10. Dujardin, 1835, Mémoire sur les couches du sol en Touraine, et description des coquilles de la craie et des faluns: Mém. Soc. géol. France, v. 2, p. 211-312.
11. *see* Lyell, 1833, Principles of Geology, v. 3, chapt. 5.

ACKNOWLEDGMENTS

We thank Dr. Hubert C. Skinner for providing the copy of the French *Elements* that we used, and for commenting on an earlier version of our paper. We also thank Dr. Leonard G. Wilson, who made several very useful suggestions for the improvement of the final version.

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Reproduction of Appendix to the first edition, french translation, of Elements of Geology – *Éléments de Géologie*, Lyell, 1839.

APPENDICE.

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Dans le treizième chapitre de cet ouvrage, j'ai dit que les additions importantes qui avaient été faites aux collections de coquilles vivantes et de fossiles tertiaires, dans le cours de ces dix dernières années, avaient rendu nécessaire la révision de cette partie de la classification des formations tertiaires qui repose principalement sur la proportion relative d'espèces récentes trouvées à l'état fossile dans chaque groupe.

Depuis que le chapitre ci-dessus mentionné de l'édition anglaise a été imprimé, je me suis empressé de faire des recherches à ce sujet; et déjà ces recherches m'ont conduit à la modification et à l'amplification de quelques-unes de mes premières idées, — changements dont je vais essayer de donner, dans cet Ap-

pendice, l'explication d'une manière aussi abrégée que possible.

D'après des investigations récentes, il paraît que le Crag anglais, que j'ai rapporté en totalité à la formation Pliocène ancienne (Voyez p. 349), appartient à diverses périodes, savoir : le Crag Rouge et le Crag Corallin de Suffolk, dont les fossiles représentés pages 353-356, sont caractéristiques, à l'époque Miocène; et le Crag de Norwick seul à la période du vieux Pliocène. Les considérations suivantes ont déterminé ce changement d'opinion.

1° Les lits coquilliers de sable et d'argile que l'on a désignés sous le nom de Crag, et qui, dans le comté de Norfolk, reposent sur la craie, consistent en un dépôt fluvio-marin, lequel a fourni 90 espèces environ de coquilles marines, et 20 à peu près de coquilles terrestres et d'eau douce. Parmi ces coquilles, le nombre des espèces récentes est, quant à présent, dans la proportion de 50 à 60 pour cent. Cette formation peut donc être attribuée à la période Pliocène ancienne, dans laquelle je plaçais autrefois tout le Crag anglais.

2° Les coquilles fossiles du Crag Rouge de Suffolk figurent au nombre de 214, à l'exclusion des annulata et des cirripeda, dans la collection de M. Searles Wood. Sur ce nombre, 64 appartiennent à des espèces récentes, ce qui établit, à l'égard des espèces éteintes, une proportion de 30 pour cent environ.

3° Dans la même collection, sur 329 coquilles pro-

venant du Crag Corallin, les espèces récentes sont au nombre de 62, c'est-à-dire dans le rapport de 19 pour cent.

Je fus aidé dans ces comparaisons de coquilles fossiles et récentes par deux naturalistes très-distingués: M. Searles Wood, qui possède une connaissance très-approfondie des coquilles Britanniques tertiaires; et M. G.-B. Sowerby, dont les connaissances, en fait de coquilles récentes surtout, sont justement appréciées par tous les conchyliologistes.

La prédominance ci-dessus mentionnée des espèces éteintes dans le Crag Rouge et dans le Crag Corallin indique une différence si grande avec la faune actuelle de la mer la plus voisine de ces deux formations, que je me sens porté à les attribuer à différentes époques de la période Miocène. Cette différence, à l'égard de la faune vivante de l'Océan Allemand, ne se borne pas aux espèces; elle s'étend aussi à plusieurs genres qui, actuellement, sont étrangers aux mers adjacentes: tels sont, entre autres, une grande Cassis, et une Voluta dans le Crag Rouge; une Pyrula, une Voluta, une Lingula, une Pholadomya et une Glyximeris, dans le Crag Corallin. On rencontre aussi dans ce dernier dépôt plusieurs coraux (*Stone-corals*), dont l'une des espèces appartient au genre intertropical Anthophyllum.

Après avoir, en 1825, soigneusement examiné le Crag de Suffolk et les faluns de la Touraine, M. Desnoyers déclara que, suivant son opinion, ces deux

formations devaient être d'origine contemporaine. Cette conclusion, que je considère aujourd'hui comme étant fort probable, a, dans le principe, été combattue par moi sous le double rapport de la grande proportion supposée de coquilles récentes dans le Crag de Suffolk, et de la distinction presque complète qui existe entre les espèces de coquilles fossiles de la Touraine et celles de Norfolk et de Suffolk. Le premier de ces arguments était fondé sur une erreur, laquelle, à son tour, résultait principalement de ce que les coquilles du Crag de Norfolk le plus récent étaient confondues avec celles de Suffolk, et attribuées à la même période, — circonstance qui donnait pour la proportion des coquilles récentes un chiffre plus élevé que celui qui convient pour le Crag Rouge ou pour le Crag Corallin de Suffolk, pris chacun séparément. L'autre argument, savoir, la distinction des espèces fossiles de Suffolk et de la Touraine, présente encore une très-grande difficulté, puisque sur cent de ces espèces, il n'y en a pas dix qui soient communes aux deux formations.

Après avoir examiné, conjointement avec M. G.-B. Sowerby, une collection de 236 espèces de coquilles de Touraine, réunies par M. Dujardin, et décrites par lui dans les *Mémoires de la Société géologique de France* (Voyez cet ouvrage, tome II, page 211), nous avons trouvé que, parmi ces coquilles, la proportion des espèces récentes était de 26 pour cent. Quant aux espèces fossiles, de même que dans le Crag de Suffolk

elles étaient pour la plupart identiques à celles des régions Britanniques et des climats arctiques, de même, ici, elles se rapportaient aux espèces de la Méditerranée ou du nord de l'Afrique. On aurait dit qu'à l'époque à laquelle furent produites les deux formations en question, une barrière géographique s'étendant au travers de la Manche, servait de séparation à deux golfes, l'un ayant son ouverture du côté du nord, et l'autre du côté du sud.

M. Sowerby a aussi examiné avec moi 400 espèces de coquilles provenant des formations Eocènes marines et d'eau douce d'Angleterre. Sur ce nombre, nous n'en avons trouvé que quatre qui fussent identiques à des espèces récentes. Cette proportion de un pour cent pourra peut-être par la suite se trouver légèrement augmentée ; mais ce qui nous fait croire que dans aucun cas cette augmentation ne saurait être très-considérable, c'est que les collections de coquilles vivantes que, dans le cours de nos recherches, nous avons eu occasion de visiter, font partie des plus riches qui existent en Europe.

D'un autre côté, quelques-uns des dépôts les plus récents de l'Angleterre contiennent en coquilles, tant lacustres que marines, plus de 90 ou 95 pour cent d'espèces actuellement vivantes ; et je ne doute pas que l'on ne finisse par découvrir, dans les différents dépôts tertiaires de l'Europe, presque toutes les proportions intermédiaires entre celle qui caractérise les Strates Eocènes anglaises ci-dessus mentionnées, dans

lesquelles il se trouve à peine un pour cent d'espèces récentes ; et le terme opposé, qui donne tout au plus la même proportion d'espèces éteintes. Déjà, trouvant qu'il devient nécessaire d'établir une ligne de démarcation arbitraire entre les dépôts auxquels j'ai donné les noms d'Ancien et de Nouveau Pliocène, je rapporterai à ceux-là, c'est-à-dire aux plus anciens de ces groupes, les strates qui contiennent de 40 à 70 pour cent d'espèces récentes de coquilles ; et aux plus modernes, ceux dans lesquels cette proportion excède 70.

Toutefois, en même temps qu'il est devenu nécessaire de subdiviser les deux périodes ci-dessus mentionnées, j'ai trouvé que les termes destinés à désigner ces subdivisions étaient d'une longueur incommode, et je me suis proposé d'employer à l'avenir le mot Pliocène pour Ancien Pliocène, et de substituer à la dénomination de Nouveau Pliocène celle plus abrégée de *Pleistocène*, tirée du grec pleiston, *plus*, et kainos, *récent*.

REVIEWS

FOSSILS FOR AMATEURS: A Guide to Collecting and Preparing Invertebrate Fossils, by Russell P. MacFall and Jay Wollin (Second Edition). Published by Van Nostrand Reinhold Company, New York, Cincinnati, Toronto, London, and Melbourne, 1983, x + 374 pp., illus.; cloth edition, $18.50; paper edition, $12.50

This volume is written for the amateur collector of fossils (as the title states) and is intended to enable the untrained collector to learn enough about fossils and geology to pursue his hobby in a meaningful and non-destructive manner and gain both knowledge and intellectual satisfaction from his pursuit. Specific contributions of amateur collectors of the past and their numerous discoveries of the remains of previously unknown animals are reviewed in the first chapter. The role of "enlightened amateurs" in the advancement of paleontology is undeniably important and the necessity of communicating with and working with professional paleontologists is stressed in this volume. This is most welcome as too many amateurs do not follow careful and proper procedures resulting in the destruction and waste of both fossil materials and their own labors.

Later chapters are concerned with the vast extent of geological time and discussions of geologic processes, the nature of fossils, fossilization processes, burrows and trails, nomenclature and classification, and types of plant and animal fossils. Subsequent chapters deal with practical procedures and techniques used in collecting, cleaning, cataloguing, and preparing the specimens for study and photography and eventual display.

The book is well written and informative, well illustrated, organized and indexed. It should be read and used by all amateur collectors.

HEN'S TEETH AND HORSE'S TOES, by Stephen Jay Gould. Published by W. W. Norton & Company, New York and London, 1983, 413 pp., illus., $15.50

Stephen Gould is one of the most popular and successful science writers presently active. His wit, sense of humor, and tasteful perception of the best way to bring science to the attention of the non-scientist is unsurpassed in modern America. The present volume is a worthy addition to his many articles and several previous books on evolution and related subjects.

The thirty chapters are arranged in seven sections: the first, *Sensible Oddities,* is concerned with curiosities in Nature; the second, *Personalities,* consists of sensitive biographical essays on three geologists (Steno, Hutton, and Cuvier) and three biologists (Agassiz, Darwin, and Vavilov); the third comprises five chapters on *Adaption and Development;* the fourth, *Teilhard and Piltdown,* is on the Piltdown Conspiracy and Man's place in Nature; the fifth, *Science and Politics,* treats creationism, race and creed; the sixth, *Extinction,* deals with the decline of dinosaurs and other items such as Hershey bars; the seventh and final section, *A Zebra Trilogy,* includes essays on zebras, the zebra's stripes, and quaggas, coiled oysters and flimsy facts.

This delightful volume is both entertaining and informative. It will be read and reread by both geologists and biologists.

GEOLOGIE DE L'EUROPE, DU PRECAMBRIEN AUX BASSINS SEDIMENTAIRES POST-HERCYNIENS, coordination de Jean Cogné et Maurice Slansky, Mémoire du Bureau de Recherches Géologiques et Minières, no. 108, Orleans, France, 1980, 308 pp., illus., paper $30.60

The *texte intégral* of *Colloque C6: Géologie de l'Europe* of the twenty-sixth International Geological Congress is presented in this volume (one of three forms of publication of these proceedings). The papers are printed in English or French and are divided into four themes: Thème I, l'Europe Pré-varisque (4 papers); Thème II, Les Grandes Régions Varisques (6 papers); Thème III, Vers une Synthèse Paléogéodynamique du Domaine Varisque (5 papers); and, Thème IV, Les Bassins Post-Hercyniens (6 papers). It comprises a valuable contribution to the regional geology of Europe.

—H.C.S.

FOSSIL HACKBERRY SEEDS FROM THE LOESS AT NATCHEZ, MISSISSIPPI

WILLIAM MILLER, III
and
LAURA ST. C. LEITCH
TULANE UNIVERSITY

The loess deposits in the vicinity of Natchez, Mississippi, have received much attention from geologists over the years, and are well known to paleontologists as the source of an abundant and varied terrestrial snail fauna (Shimek, 1902; Vestal, 1942; Russell, 1955; Snowden and Priddy, 1968; Kolb, 1976). With the exception of the casts and molds of roots, well-preserved plant remains from the southern loess are essentially unknown. The purpose of our note is to describe a rare occurrence of fossil seeds from loess deposits near Natchez, and to comment on the mode of preservation of the seeds.

During the summer of 1982, the best collecting locality for fossil land snails in the Natchez area was at the western edge of property on which the Natchez Ramada Inn motel is presently located, on the southern periphery of town. The site is 0.4 km south of the southeast footing of the Natchez-Vidalia Bridge, and 50 m west of the motel building (see Natchez, Mississippi-Louisiana 7.5′ quadrangle map, 1963). The locality consists of spoil derived locally from the loess and used to control the headward erosion of a large gully that cuts into the river bluff just west of the motel. We are sure that the fill used here is loess owing to its silty texture, buff coloration, and the presence of many pulmonate gastropod shells; we are not sure, however, of the exact stratigraphic position within the loess from which the fill was derived. In addition to fossil snail shells, this locality yielded a single calcareous siltstone nodule containing around 200 small, chalky seeds (Pl. 1, figs. 1,2).

The seeds are approximately 6 mm in diameter and divided into two equal hemispherical shells. The commissural margins of each shell are delimited to straight, continuous, raised ridges that girdle the shells and form a double equatorial band around the seeds. Shell surfaces feature an intricate pattern of reticulated ridges, with the ridges having three relatively stronger grades of relief (Pl. 1, fig. 3). The strongest grade of relief is about equal to that of the commissural ridges. Each hemispherical shell consists of a white outer wall, 0.5 mm thick, which surrounds a light-gray inner lamina about 0.05 mm thick (Pl. 1, fig. 4). Both layers have been replaced with subhedral calcite crystals that are best exposed along the freshly broken edges of shells (Pl. 1, fig. 5). Some of the fossil seeds contain microscopic, light-brown, acicular to irregularly shaped bodies of calcite attached to the inner laminae. Based upon size, shape, and surface sculpture, the seeds closely resemble hackberry (*Celtis* sp.) seeds (see Martin and Barkley, 1961, p. 145 and Plates 699, 700).

The seeds are embedded in a pale yellowish-brown (10 YR 6/2), clayey siltstone nodule that has been cemented with calcite and contains numerous, small rootlet channelways (Pl. 1, fig. 2). Fresh loess exposures in the Natchez and Vicksburg areas that were studied by Snowden and Priddy (1968), and later by Kolb (1976), contained similar calcareous nodules associated with paleosols. These ancient soil horizons are located both between major loess sheets and within these units. It appears that during both short and protracted pauses in the deposition of the wind-blown silt deposits of the lower Mississippi Valley, soils mantled the newly deposited loess blankets. Trees, bushes, and grasses colonizing loess-covered uplands adjacent to the river valley contributed organic material to these thin soil covers, and were buried along with the soils by each of the subsequent pulses of eolian deposition. These paleosols probably represent poorly developed, slightly alkaline soil horizons (see Daniels *et al.*, 1960; Snowden and Priddy, 1968, p. 109-117), in which plant material occasionally could be replaced with calcite. The calcite was ultimately de-

rived from windblown calcareous rock flour (which originally made up a small percentage of the silt deflated from the adjacent Mississippi Valley floor) and from pedochemical recycling of $CaCO_3$ from snail shells within the loessial blankets. These nodules and paleosols may therefore prove to be productive targets for collecting additional examples of plant fossil remains in the southern loess.

We would like to thank Ms. Deborah Sellers for presenting the nodule containing the fossil seeds. Ms. Lisa Metelman skillfully prepared the micrographs using the Department of Geology scanning electron microscope at Tulane University.

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October 31, 1984

PLATE 1

Figures

1. Calcareous siltstone nodule containing fossil hackberry (*Celtis* sp.) seeds. (Bar scale represents 5 cm)
2. Freshly broken edge of siltstone nodule showing fossil seeds concentrated in thin layer. Noterootlet channelways (small dark holes). (Same scale as in fig. 1)
3. External view of individual seed. (Bar scale represents 1mm)
4. Internal view of seed shell showing the continuous outer wall (indicated by black arrows) and the discontinuous inner lamina (white arrows). (Bar scale represents 1 mm)
5. Close-up view of broken surface of shell wall showing subhedral calcite crystals. (Bar scale represents 10 microns)

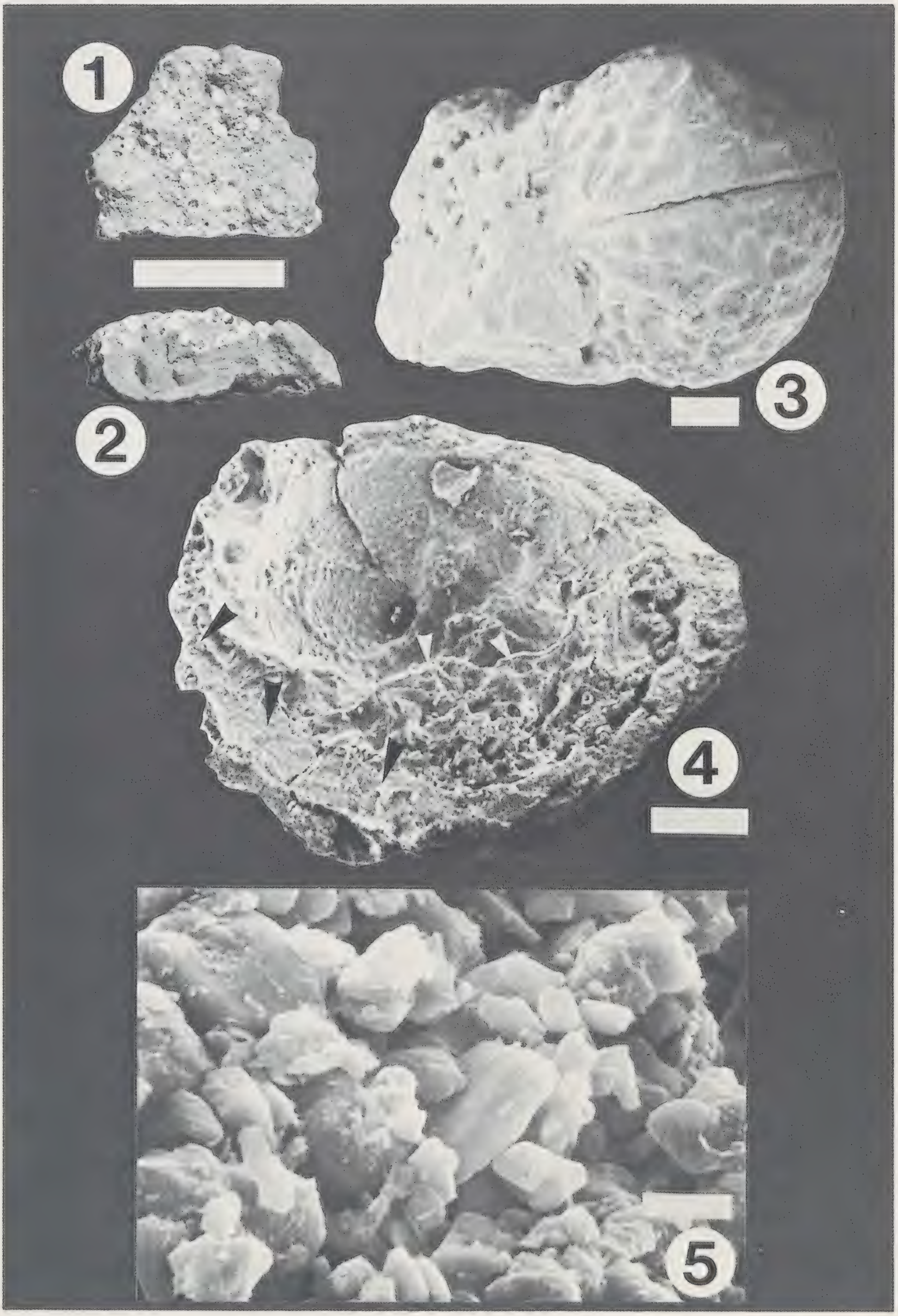

PLATE 1

REVIEWS

ASPECTS OF THE ORDOVICIAN SYSTEM, edited by David L. Bruton. Palaeontological Contributions from the University of Oslo, no. 295, published by Universitetsforlaget, Oslo, Bergen, Stavanger and Tromso, and distributed by Columbia University Press, New York, 1984, viii + 228 pp., Illus., paper $19.00

The proceedings of the Fourth International Symposium on the Ordovician System, held in Norway in 1982, are presented in this volume. Twenty-one papers by twenty-nine authors, dealing with the Stratigraphical Framework (3), Ordovician Sea Level Changes (3), Ordovician Climate (2), Ordovician Shelly Environments (5), Ordovician Graptolitic Environments (3), and Ordovician Volcanic Environments (4), follow the Introduction "What is so special about the Ordovician?"

The symposium organized by the "Friends of the Ordovician" was designed to include aspects of the Ordovician System such as global transgressions and regressions, climate, and vulcanicity which have been given scant attention in the past but which have great significance to the more commonly studied stratigraphy and faunas of the System. Thus, some of the contributions in this important volume present information and subjects relatively new to the published literature.

GEOLOGY AND PALEONTOLOGY OF SOUTHEAST ASIA, Volume 23, edited by Teiichi Kabayashi, Ryuzo Toriyama, and Wataru Hashimoto. Published by University of Tokyo Press, Tokyo, and distributed by Columbia University Press, New York, 1982, viii + 206 pp., 3 folding pls., 19 tbls., atlas of 19 plates, $59.50

This, the twenty-third volume of the series begun in 1964, comprises nine articles by eleven authors from the Philippines, Thailand, and Japan. Three articles are on the geology and palaeontology of Thailand, two are on Malaysia, and three are on the Philippines; the last article is a review of the fossil records from East Malaysia and Brunei. Among the contents are reports of an aberrant fusuline structure and a new genus, *Pravitoschwagerina,* from Thailand, the Triassic conodont stratigraphy of West Malaysia, Jurassic fossil wood of Thailand, Jurassic and Cretaceous ammonites of Sarawak, Philippine Tertiary stratigraphy, and two articles on the Miocene molluscan faunas of the Philippines. Taxonomic descriptions include three new species of conodonts, five new species of Mollusca, and the new genus of foraminifer. The series is well-illustrated, informative, and a worthy addition to the knowledge of Southeast Asian geology and paleontology.

A STRATIGRAPHIC STUDY OF LATE WEICHSELIAN DEGLACIATION, SHORE DISPLACEMENT AND VEGETATION HISTORY IN SOUTH-EASTERN SWEDEN, by Svante Björck. Fossils and Strata, no. 14, published by Universitetsforlaget, Oslo, and distributed by Columbia University Press, New York, 1982, 93 pp., illus., paper $22.00

This publication is part of *Fossils and Strata,* an internationally distributed series of monographs and memoirs in palaeontology and stratigraphy. It is a companion series to the journals *Boreas, Lethaia,* and *Lithos.*

Late Weichselian pollen stratigraphy and chronostratigraphy of sediments from sixteen lakes or peat-bogs in Blekinge, south-eastern Sweden were related to the deglaciation pattern, Late Weichselian sedimentation, chronology, and shore displacement. These studies have revealed at least two transgressions and two drainage events. Local and regional lithostratigraphic units for Pleistocene deposits in Blekinge are described and defined. A paleoclimatic synthesis, based on bio- and lithostratigraphy was made for the Late Weichselian interval in Blekinge. It has proved possible to correlate the Late Weichselian geological history in Blekinge with parts of the Baltic Basin and also with the deglaciation of other parts of Southern Sweden.

--H.C.S.

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THE FLANNER BEACH FORMATION (MIDDLE PLEISTOCENE) IN EASTERN NORTH CAROLINA

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"If the entire Neogene section of southeastern North Carolina and northeastern South Carolina were exposed in the Grand Canyon, it would probably be assigned to one formation"

Wallace C. Fallaw, *in litt.*
5 May, 1983

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I. ABSTRACT

The Flanner Beach Formation was deposited along the Atlantic Coast of east-central North Carolina during a high stand of world sea-level about 200,000 years B.P. This major barrier-lagoon sequence can be divided into three members in its type area along the lower reaches of the Neuse River: 1) Smith Gut Member (new unit), deposited in early transgressive open-bay settings; 2) Arapahoe Sand Member (newly formalized unit), deposited in a barrier-island complex as the rate of sea-level rise decreased; and 3) Beard Creek Member (newly formalized unit), composed of sediments that accumulated in a spatial-temporal mosaic of bay and lagoonal environments. The barrier-sand lithosome is continued to the south of the Neuse valley as the Newport Sand Member (newly formalized unit).

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Time-equivalent deposits cropping out in the Pamlico River valley, 40 km north of the Flanner Beach type area, also are divisible into three units of member rank: 1) Hills Point Member (new unit), deposited in isolated lagoonal or river-estuary settings; succeeded vertically by 2) Mauls Point Member (new unit), deposited in more open lagoonal areas; and 3) a poorly exposed, unnamed member resembling the Beard Creek Member.

II. INTRODUCTION

The Flanner Beach Formation in particular and the lower Neuse River area in general have been the focus of many stratigraphic and paleontologic investigations. The purpose of this report is to provide an up-dated description of the Flanner Beach Formation, based upon both a review of recent studies and on field work undertaken in the Neuse and Pamlico River valleys in Summer, 1982, as a part of a dissertation completed recently at Tulane University.

The earliest of stratigraphic studies of Pleistocene beds cropping out along the Neuse River dates back to the early nineteenth century. Publications resulting from these studies were written by some of the more illustrious figures in the history of Atlantic Coastal Plain geology, including T.A. Conrad, W.H. Dall, and W.C. Mansfield. The interested reader should consult reviews of pre-1960's investigations appearing in Mansfield (1928), Richards (1950), Fallaw (1965), and DuBar *et al.* (1974). More recent literature is reviewed in the first part of this report.

Notwithstanding Professor Fallaw's admonition (epigraph), as a result of my field work, I recognize and describe new members within the Flanner Beach and identify time-equivalent deposits in the Pamlico River valley of Beaufort County. Informal members mapped and described by Mixon and Pilkey (1976) are promoted to the status of formal lithostratigraphic units and the environmental history of the Flanner Beach Formation is reconstructed using lithologic characteristics, physical and biogenic sedimentary structures, lateral and vertical facies relationships, relationship of deposits to surface morphologic features and to disconformities (where applicable), paleontologic data, and results of a limited number of oxygen-isotope analyses.

III. ACKNOWLEDGMENTS

This study was part of a doctoral dissertation completed at Tulane University, under the supervision of Emily H. Vokes. Field work was supported by grants from the Geological Society of America and the Society of the Sigma Xi (Tulane University Chapter). Funds for oxygen-isotope ratio analyses were provided by the Graduate School, Tulane University. Thomas M. Cronin provided important, unpublished information on time-correlation and age of the Flanner Beach Formation. Doc Brown and Clay Carter provided motorboat transportation to several study sites that would have been otherwise inaccessible. Laura Leitch patiently prepared the photographs and Darren Trotter carefully typed the manuscript. To all these individuals and institutions I express my sincere gratitude. My special thanks go to Drs. Jules R. DuBar, Wallace C. Fallaw, and Walter H. Wheeler for providing thoughtful, thorough reviews of this paper. Naturally, the observations and interpretations expressed herein are my own and I take full responsibility for them.

IV. METHODS

Eleven stratigraphic sections were measured and described from bluff-line exposures: four from the bluff-line extending along the north shore of the Neuse, four from the south shore of the Neuse and three from bluffs that surround Blounts Bay on the south shore of the Pamlico River (Figure 1). Beds were traced between bluff-line localities by directly walking out exposures or by making frequent landfalls using a motorboat. Field descriptions of lithostratigraphic units appear in the Appendix. Bulk fossiliferous sediment samples were collected at Whisk Point and Smith Gut, in southern Pamlico County, and used in a detailed paleoecologic analysis of the formation (Miller, 1984, and in preparation). From these samples, specimens of *Mulinia lateralis* valves were selected at critical stratigraphic elevations for use in oxygen-isotope analyses.

V. REVIEW OF RECENT INVESTIGATIONS

Neuse River Valley Area

Dubar and Solliday (1963) restudied the Neuse River exposures and decided to abandon the older stratigraphic nomenclature in favor of formation names based on carefully described type sections. They argued that "Pamlico formation" was an inappropriate name because no type section was ever described by Stephenson (1912, p. 286-290) and because they wished to abandon the tradition of using the same name for both a coastwise terrace surface and for the sediments that underlie it (*i.e.*, the "terrace-formation" concept). They proposed the new name "Flanner Beach Formation" for the youngest deposits cropping out along the lower Neuse River, between Johnson Point and Hancock Creek, downstream from New Bern, Craven County. The type section was located at the Flanner Beach Recreation Area

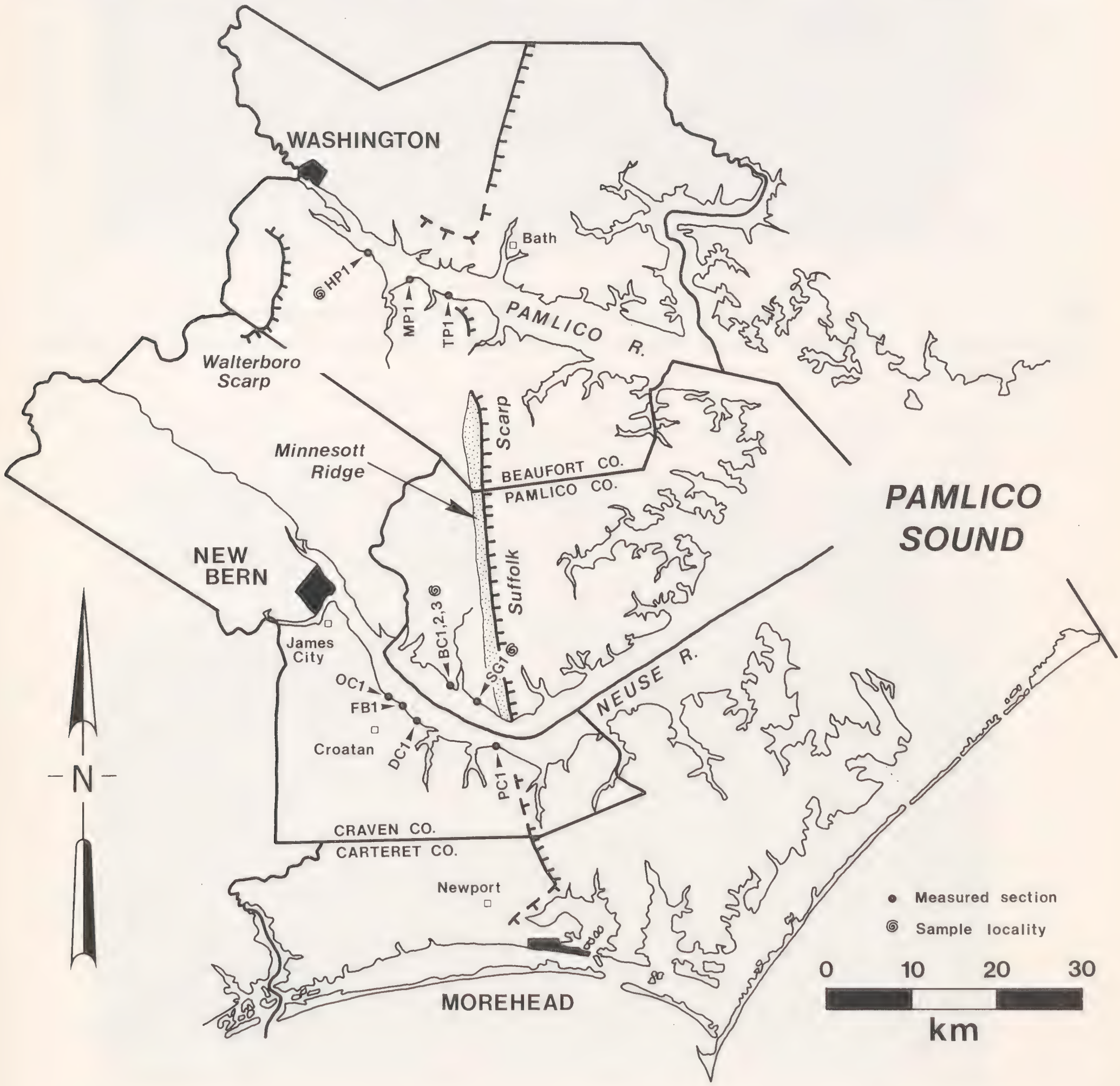

Figure 1. Map showing locations of measured sections along the Neuse and Pamlico Rivers in eastern North Carolina. Measured section numbers correspond to those used in Figures 5, 6, and 7, and in the Appendix.

Figure 2. The cypress-stump bed at Flanner Beach Recreation Area, Craven County. Contact with overlying Flanner Beach Formation is shown with arrows. The ruler is about 1 m long.

Figure 3. The Suffolk (or Grantsboro) Scarp just south of Arapahoe, Pamlico County. View is toward the west and the intersection of N.C. Highway 306 (in the distance) with County Road 1302 (foreground). *T*, edge of the Talbot geomorphic surface at +11.6 m MSL; *t*, toe of the scarp at about +8.0 m MSL

(DuBar and Solliday, 1963, p. 231-232; DuBar *et al.*, 1974, p. 121). The popular name "Croatan sand" was suppressed because no type section had been described by Dall (1892), who used the name "Croatan beds" informally; as originally delineated, the unit contained at least two formational units; and because Mansfield (1928) had later misidentified Pleistocene beds as Pliocene Croatan sand, owing to older fossils being reworked into a younger, superjacent unit. They proposed the name "James City Formation" to replace Croatan sand. The newer terminology applied by DuBar and Solliday (1963) has stood the test of time and subjective stratigraphic revision, and their formational nomenclature has been adopted essentially intact by the United States Geological Survey (Mixon and Pilkey, 1976; Blackwelder, 1981b).

More recently, Fallaw (1965, 1973) and Fallaw and Wheeler (1969) used the name "Neuse Formation" for all of the fossiliferous marine sediments of Late Pleistocene age occurring in southeastern North Carolina. This is more or less the concept of "Pamlico formation" used by Richards (1936, 1950, 1962, 1965). Although their detailed sedimentologic examinations of Pleistocene beds exposed along both sides of the Neuse River represent an important contribution, the stratigraphic labels employed by these workers have not been adopted. Their Neuse Formation in the Neuse Valley is equivalent to the Flanner Beach Formation, excluding sandy beds occurring near the surface in the Beard Creek area of Pamlico County, which they called "surficials," and the cypress-stump bed at Flanner Beach (Figure 2), for which they revived the name "Horry Clay." They also favored retaining the name "Croatan Formation" for subjacent fossiliferous beds, which they believed to be Pliocene in age.

Another recent reinterpretation of stratigraphic relationships and nomenclature was made by Daniels *et al.* (1972), who used the names "Talbot" and "Pamlico morphostratigraphic units" for Pleistocene sediments directly underlying the extensive plains west and east, respectively, of the Suffolk (or Grantsboro) Scarp, which extends north-south across the Pamlico-Neuse interfluvial divide (Figures 1, 3).

Figure 4. The top of the Flanner Beach Formation (Talbot geomorphic surface) in south-central Beaufort County. View is toward south from N.C. Highway 33, about 11 km west of Edward.

They placed the cypress-stump bed and underlying shelly beds (= James City Formation) within their "Small sequence." Although these authors may have muddied the waters slightly by returning to the older terrace-formation terminology and by inventing the "Small sequence," they made an important contribution to the understanding of Quaternary stratigraphic relationships in the region by tracing, for the first time, units beneath the Pamlico-Neuse divide north of well-studied outcrops in the Neuse valley, and by describing stratigraphic cross-sections compiled from power-auger traverses across the Suffolk Scarp and Minnesott Ridge at several localities (Daniels *et al.*, 1972, figures 3, 5, 8, 9). The most recent version of this work is presented in Wheeler *et al.* (1983).

In 1974, DuBar *et al.*, presented a thorough account of the Quaternary stratigraphy in the Neuse valley, as currently understood, and listed fossils from the Flanner Beach and James City Formations. They reconstructed the post-Miocene environmental history of the area based on physical stratigraphy, relationship of lithologic units to landforms, and on general paleoecologic data. They used the informal name "Cherry Point unit" for sand cropping out at the Pine Cliff Recreation Area, Craven County, which they thought overlay and post-dated the Flanner Beach Formation (*cf.* "Arapahoe sand member" of the Flanner Beach Formation, Mixon and Pilkey, 1976).

The most recent series of studies relating to the Flanner Beach and James City Formations have dealt with the larger patterns of regional correlations and relationships between Atlantic Coastal Plain depositional cycles and changes in Late Cenozoic world climate (Akers, 1972; Liddicoat *et al.*, 1979; Cronin, 1980, Blackwelder, 1981a, b, c; Cronin *et al.*, 1981; McCartan *et al.*, 1982; Wehmiller and Belknap, 1982).

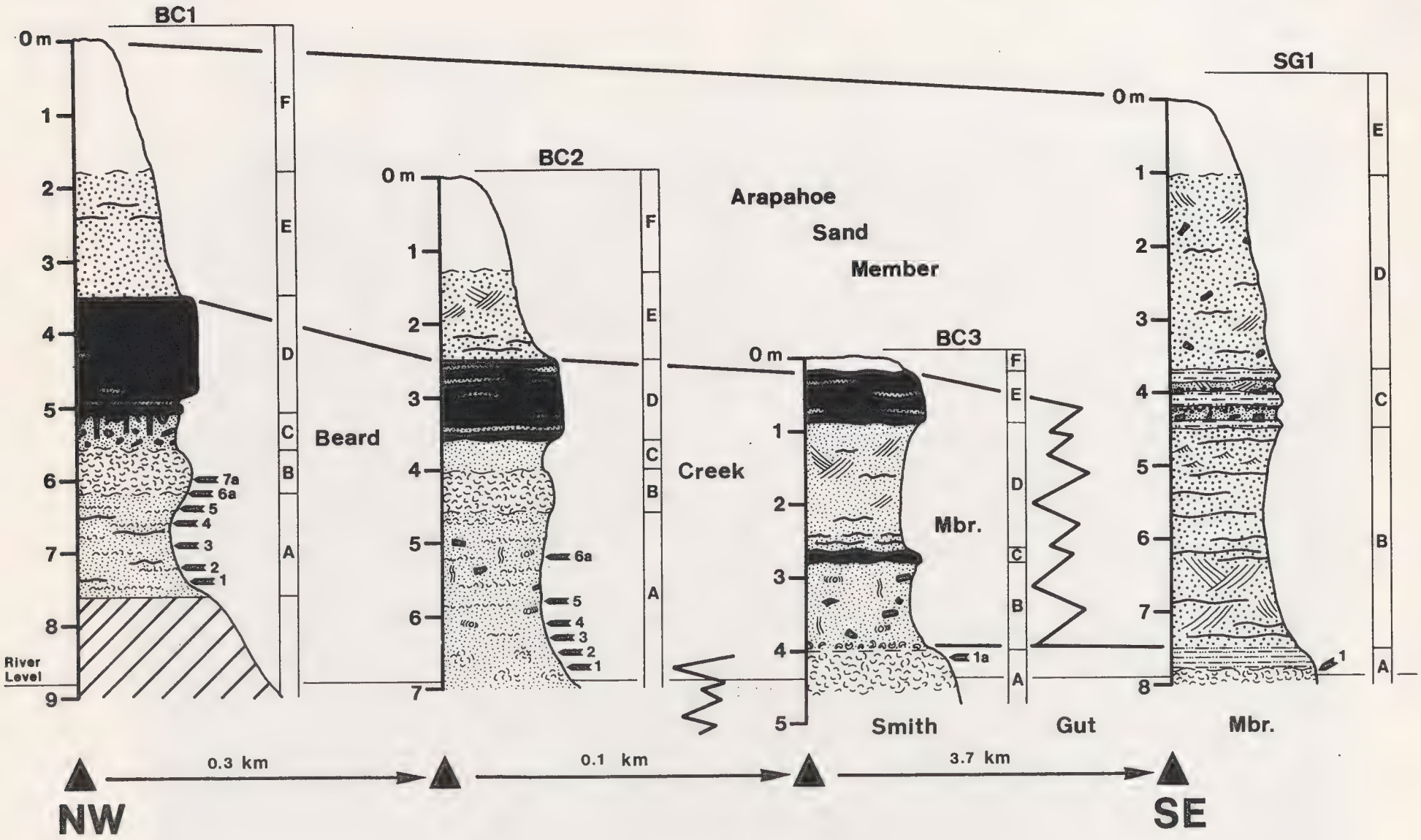

Figure 5. Stratigraphic panel-diagram of bluff-line exposures along north shore of Neuse River, Pamlico County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix, and arrows with numbers show stratigraphic levels from which bulk samples were collected for paleoecologic analyses. All symbols used in columns are explained in Figure 8.

Pamlico River Valley Area

Other than a reconnaissance of the stratigraphy of the bluffs along the south shore of the Pamlico River (Austin, 1973; Austin *et al.*, 1973), and an investigation of patterns of shoreline erosion in this area (Bellis *et al.*, 1975), the northern equivalents of the Flanner Beach Formation have remained essentially unstudied. My search for fossil deposits in the Pamlico valley provided the opportunity to examine and describe these bluff-line exposures (Miller, 1984).

A new description of the stratigraphy and paleontology of beds exposed in the Texasgulf, Inc., stripmine at Lee Creek in eastern Beaufort County (Ray, 1983) provides some of the latest information on units occurring to the east of, and on units situated stratigraphically below, the Flanner Beach deposits in the Pamlico-Neuse interfluvial divide. In this collection of papers, the contribution by Belt *et al.* (1983) includes a description of an environmental stratigraphic unit, their "current unit" of possible middle Pleistocene age, that may be a time-equivalent of the Flanner Beach Formation.

VI. STRATIGRAPHY OF THE FLANNER BEACH FORMATION

General Characteristics

The Flanner Beach Formation is the surface unit in the vicinity of the Neuse and Pamlico Rivers where elevations range from about +7 to +12 m MSL (Mean Sea Level). The top of the formation is typically a flat and poorly-drained plain known as the "Talbot geomorphic surface" (Daniels *et al.*, 1972), having an average elevation of about +11 m MSL (Figure 4). The main body of the formation appears to extend from the toe of the Walterboro Scarp in the west, to the crest of the Suffolk (or Grantsboro) Scarp in the east (Figure 1). Up-valley fluvial equivalents of the paralic Flanner Beach deposits no doubt are to be found occurring along the Tar, Trent, and upper Neuse Rivers west of the Walterboro Scarp; marine equivalents appear to occur in some instances in the shallow subsurface just east of the Suffolk Scarp (Daniels *et al.*, 1972, figure 9; Belt *et al.*, 1983; Wheeler *et al.*, 1983, figure 11; T.M. Cronin, *in litt.*, 9 May, 1983). This shows that the Flanner Beach is closely associated with the Talbot

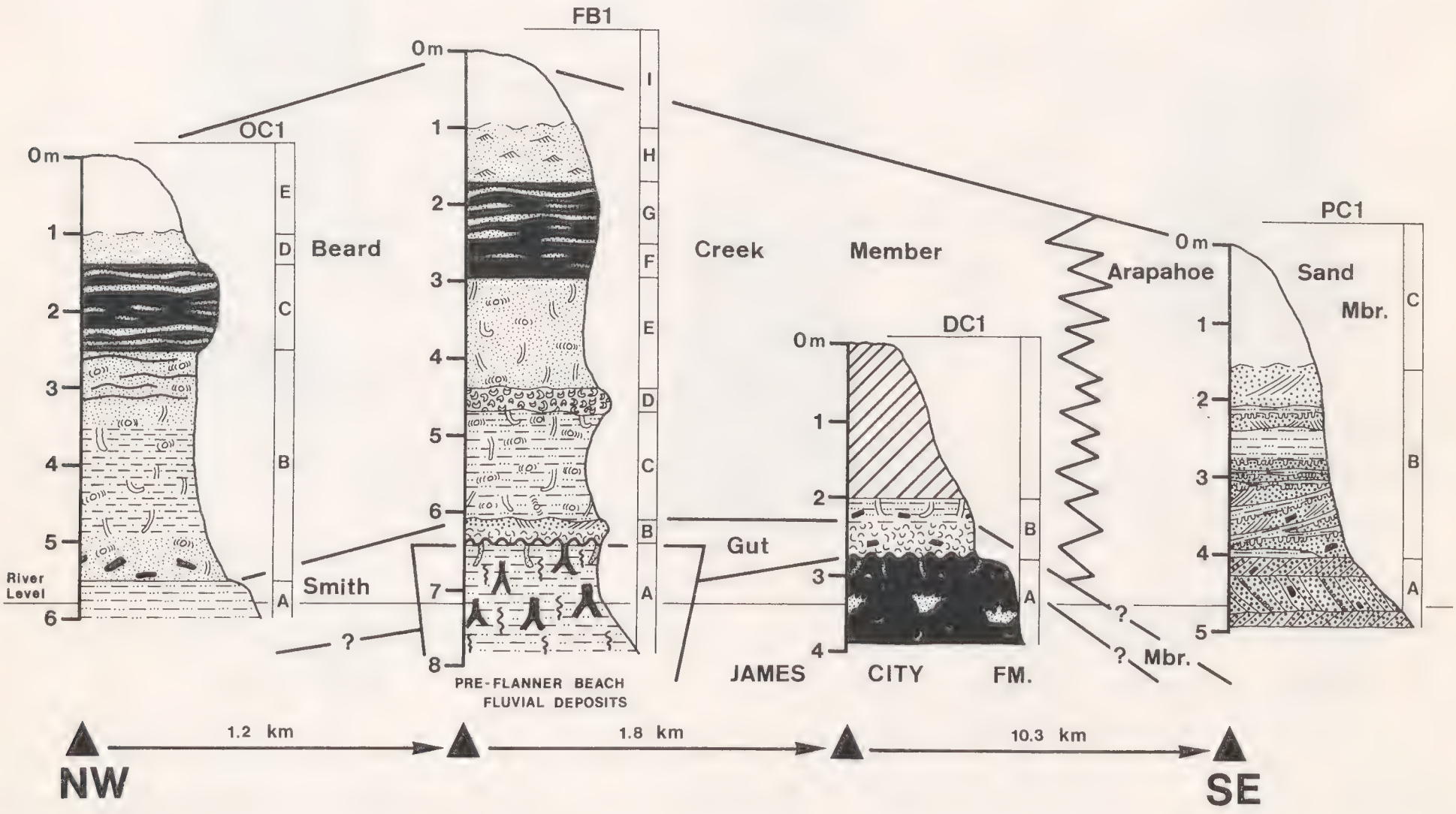

Figure 6. Stratigraphic panel-diagram of bluff-line exposures along south shore of Neuse River, Craven County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix. All symbols used in columns are explained in Figure 8.

surface, which appears to be the preserved surface of a sediment-filled lagoon, but is not exactly coextensive with it. Farther to the east, beneath the Outer Banks, subsurface evidence suggests that Flanner Beach equivalents in this area have either been removed by erosion or are lithostratigraphically unrecognizable (see Herbert, 1978; Susman and Heron, 1979). The Walterboro Scarp appears to be an abandoned mainland shoreline formed during deposition of at least part of the Flanner Beach Formation; whereas the Suffolk Scarp (Figure 3) in the vicinity of the Pamlico and Neuse Rivers is a regional landform post-dating the unit, and resulting from a complex history of shoreline reoccupation that eroded and truncated the eastern portion of the Flanner Beach Formation (Daniels *et al.*, 1972, 1977; Mixon and Pilkey, 1976).

The Flanner Beach Formation, in the vicinity of the Neuse River, can be subdivided into four members, three of which have been informally named and mapped by Mixon and Pilkey (1976, p. 9-18, Plate 1). The three named subdivisions are: 1) the Arapahoe Sand Member, comprising barrier-island deposits within the Flanner Beach on either side of the Neuse River; 2) the Newport Sand Member, consisting of similar, geographically disjunct barrier sands underlying ridge-and-swale topography just south of the Newport River in

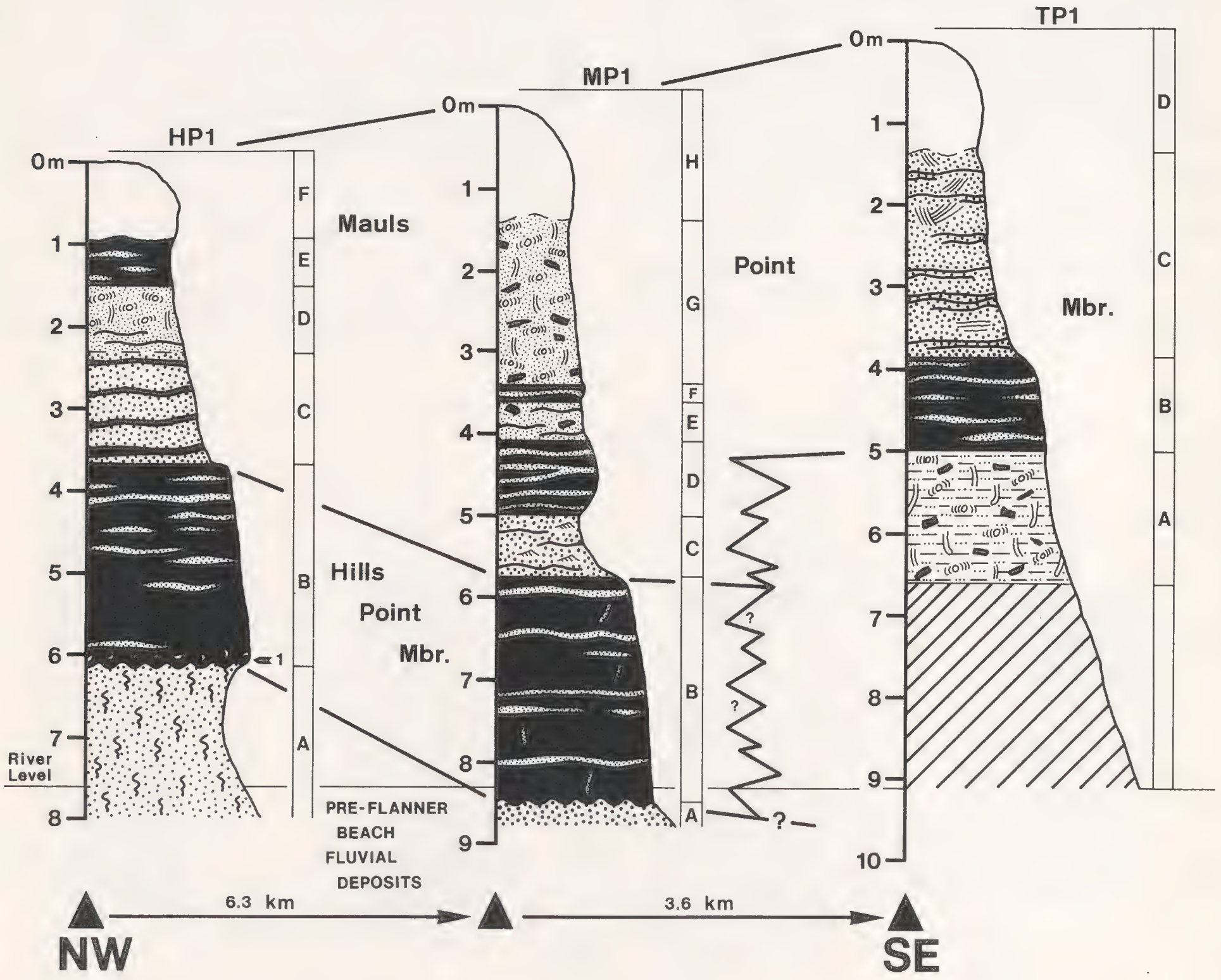

Figure 7. Stratigraphic panel-diagram of bluff-line exposures in Blounts Bay area, south shore of Pamlico River, Beaufort County, N.C. Exact locations of measured sections are shown in Figure 1 and described in Appendix. Bed letters are same as those used in Appendix, and arrow with number in column HP1 shows stratigraphic level from which bulk sample was collected for paleoecologic analysis. All symbols used in columns are explained in Figure 8.

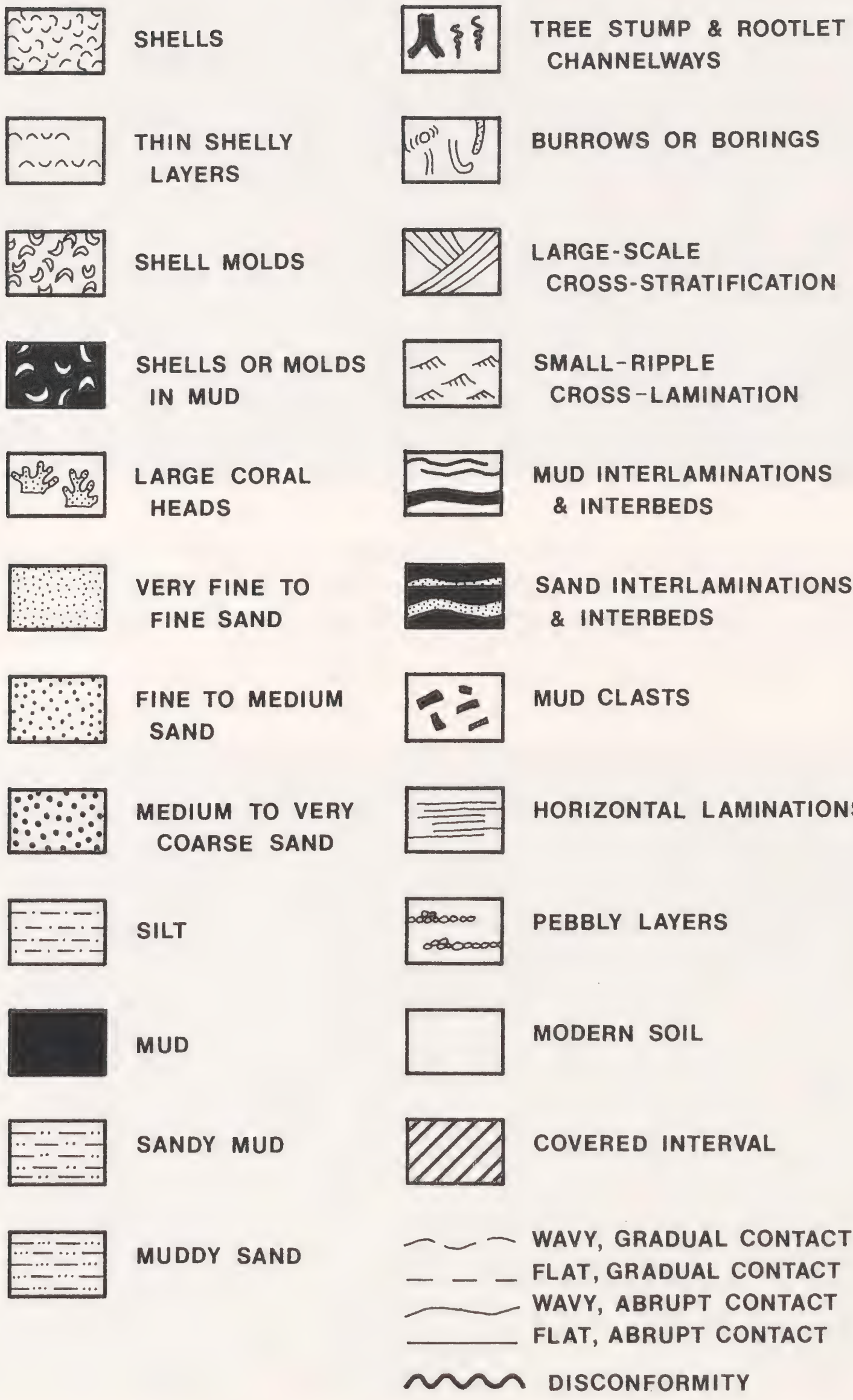

Figure 8. Explanation of symbols used in Figures 5, 6, and 7.

Figure 9. Cross-stratified sand (light) and muddy sand (dark) in the Arapahoe Sand Member at Pine Cliff Recreation Area, Craven County, N.C. (This is bed B, measured section PC1 in Figure 6 and Appendix.) Trowel is approximately 25 cm long.

Figure 10. Close-up view of contact between a muddy sand (dark) and a clean sand (light) layer in the Arapahoe Sand Member (same location as Figure 9). Note burrows filled with muddy sand near the contact; other, less distinct burrows can be seen in the sand near bottom of photograph.

Figure 11. Bluff-line at Whisk Point, Pamlico County, N.C., immediately west of Beard Creek. Darker, lower portions of bluff correspond to exposures of the Beard Creek Member and lighter upper portions correspond to exposures of the Arapahoe Sand Member. A gradual facies change within the Beard Creek Member begins near the center of the photograph, where muddy sand beds to the west (left) start to give way to cleaner sand beds with fewer silt-clay interbeds and laminations to the east (right).

Figure 12. Exposure of Flanner Beach Formation at Whisk Point, Pamlico County, N.C. (near measured section BC3 in Figure 5). Head of digging tool rests on top of Smith Gut Member.

Figure 13. Shelly lenses composed almost entirely of the mactrid clam *Mulinia lateralis*, Beard Creek Member, Whisk Point, Pamlico County, N.C. (This is typical of upper part of bed A, measured sections BC1 and BC2, in Figure 5 and Appendix.) Ruler is 15 cm long.

Figure 14. Thick shell-bed within the Beard Creek Member (bed B, measured sections BC1 and BC2, Figure 5 and Appendix), Whisk Point, Pamlico County, N.C. Most of the shells are *Mulinia lateralis* and *Ensis directus*. Ruler is about 3 cm wide.

Carteret County; and 3) correlative, fossiliferous, muddy sand and mud backbarrier deposits of the Beard Creek Member. It is proposed here to raise these informal units to the status of formal lithostratigraphic subdivisions of the Flanner Beach Formation. Only the Beard Creek and Arapahoe Sand Members are well exposed along the Neuse River (Figures 5, 6, 8). A fourth, previously unnamed, subunit cropping out beneath the Newport Sand Member 1.6 km north of the village of Broad Creek, Carteret County, consisting of shelly, muddy sand and representing the basal beds of the formation, also crops out on the Neuse near Smith Gut, Pamlico County (Mixon and Pilkey, 1976, pp. 13, 15). This distinctly different lithologic subdivision of the Flanner Beach Formation is herein named the "Smith Gut Member," and bluffs located 0.3 km northwest (upstream) of Smith Gut (measured section SG1, Figure 1) are designated as the type locality. The type section is described in the Appendix and illustrated in Figure 5. The locality labeled SP-1 near Broad Creek, Carteret County, by Mixon and Pilkey (1976, figure 3) can be regarded as a reference section for the Smith Gut Member.

Based upon my field work along the south shore of the Pamlico River in the vicinity of Blounts Bay, and on subsurface mapping by Daniels *et al.* (1972, 1977) across the Suffolk Scarp in the Pamlico-Neuse interfluve, it appears that beds equivalent to the Flanner Beach Formation also crop out in the Pamlico valley (Figures 7, 8). The Blounts Bay exposures were described by Austin *et al.* (1973), but no lithostratigraphic units were formally named and delineated. I propose here that sands and muds, which crop out in the bluff-line between Chocowinity Bay and Tripp Point, south shore of the Pamlico River, Beaufort County (see Hackney and Blounts Bay 7.5′ quadrangles), be assigned to the Flanner Beach Formation of DuBar and Solliday (1963), and Mixon and Pilkey (1976). This assignment is based on comparable lithologies, elevations, and stratigraphic relationships with other units.

The Flanner Beach Formation in the Pamlico valley also is divisible into members, two of which are well exposed and can be traced throughout the Blounts Bay area (Figure 7). The upper portion of the Flanner Beach in this area is a sandy subunit with silt-clay interbeds, herein named the "Mauls Point Member." The bluffs located 1.2 km southwest of Mauls Point on the southeastern shore of Blounts Bay, Beaufort County, are designated as the type locality (measured section MP1, Figure 1). The type section is described in the Appendix and illustrated in Figure 7. Clayey-silt to silty-clay beds that conformably underlie the Mauls Point Member are herein named the "Hills Point Member." Bluffs located 0.2 km upstream from Camp Hardee near Hills Point, south shore of the Pamlico River, Beaufort County, are designated as the type locality (measured section HP1, Figure 1). The type section is described in the Appendix and illustrated in Figure 7. A thick burrow-mottled, muddy-sand unit, poorly exposed in the lower parts of bluff-faces between Tripp Point and Nevil Creek is another distinct lithologic subdivision (measured section TP1; Figures 1, 7).

Depositional Environments – Neuse River Valley

Most of the Flanner Beach Formation was deposited in a patchwork of nearshore environments of a major barrier-lagoon coastal complex. My interpretations of the depositional environments for each member of the formation are given below.

Smith Gut Member. – Pebbly, shelly, muddy sand, in places lying directly on the James City-Flanner Beach disconformity, appears to be a basal transgressive deposit of the Flanner Beach Formation. Bulk samples from the two best exposures of the Smith Gut Member on the northshore of the Neuse River (measured sections BC3, SG1; Figures 1, 5) contained many exotic, normal marine mollusks and older shells reworked from the subjacent James City Formation, as well as an indigenous, polyhaline association of mollusks (Miller, 1984). Exposed thickness of the Smith Gut is not more than about 0.5 m, and it appears that the unit is an irregular blanket-shaped deposit that becomes thicker in paleotopographic low areas and at the base of the southeastern extent of the formation. The Smith Gut would seem to represent the rapid flooding of coastal rivers

and adjacent lowlands in the region of the Neuse and Newport River valleys at the beginning of a major episode of interglacial coastal inundation. The Smith Gut Member grades upward into barrier-sands of the Arapahoe Sand Member east of Beard Creek at its type locality: West of Beard Creek and near the Flanner Beach Recreation Area, the Smith Gut grades upward and landward (?) into backbarrier muddy sands of the Beard Creek Member (Figures 5, 6).

Newport Sand Member. – This subdivision of the Flanner Beach, originally proposed as an informal unit by Mixon and Pilkey (1976, p. 9-11), was not examined in the course of my field study. These authors regarded it as a barrier-sand lithosome associated with ridge-and-swale landforms in Carteret County. The Newport Sand Member ranges in thickness from about 3 m in the northwestern part of its outcrop area to about 12 m near the village of Broad Creek in the south, and is geometrically a thin wedge that tapers to the northwest where it intertongues with the Beard Creek Member. At least the upper part of the unit, associated with convex-landward beach ridge topography, represents a local progradation of the Flanner Beach shoreline late in the depositional cycle of the formation (Mixon and Pilkey, 1976).

Arapahoe Sand Member – Cross-stratified, fine to coarse sand, with subordinate muddy sand interbeds, pebbly layers, and small cylindrical burrows, cropping out near Smith Gut and at the Pine Cliff Recreation Area (SG1, Figure 5; PC1, Figures 6, 9), is typical of the Arapahoe Sand Member. This barrier sand unit is also a thin, wedge-shaped deposit that is probably truncated on the east by the Suffolk (or Grantsboro) Scarp and intertongues to the west with the Beard Creek Member. At Whisk Point, Pamlico County (measured sections BC1 and BC2, Figure 5), the Beard Creek Member grades upward into a fine sand, about 3 m thick with occasional cross-laminations and discontinuous clay laminations, that appears to be either distal flood tidal-delta or backbarrier sandflat deposits within the Arapahoe Sand Member. The member is up to 7.5 m thick along its eastern margin near the Suffolk Scarp (Mixon and Pilkey, 1976, p. 13).

At the Smith Gut section (SG1, Figure 5),

Figure 15. Ichnofossil *Teichichnus* in the Beard Creek Member at Otter Creek, Craven County, N.C. (bed B, measured section OC1, Figure 6 and Appendix). Ruler is graduated in centimeters and millimeters.

the Arapahoe Sand consists of three beds: 1) a lower medium to coarse sand with megaripple cross-laminations in the lower half, small-ripple cross-laminations in the upper half, and clay interlaminations throughout; 2) a middle bed consisting of interbedded sandy mud and cross-laminated, pebbly sand; and 3) an upper fine to medium sand with megaripple cross-laminations, discontinuous clay laminations, and clay clasts. The sequence seems to represent shallow channel tidal-delta sands, situated above and below a thin interval of sandflat deposits. At Pine Cliff Recreation Area (measured section PC1, Figure 6), two well defined beds are exposed: 1) a lower fine to coarse sand with wedge-shaped cross-stratification sets, pebbly layers (with flat, discoid quartz pebbles up to 1 cm in diameter), and large clay clasts; grading upward into 2) a thicker sequence of interbedded fine to medium sand and muddy sand, with abundant bivalve burrows (Figure 10), large scale cross-bedding in the lower and upper parts (Figure 9), and horizontal bedding in the middle part. These beds appear to represent a succession of deep to shallow channel settings within a tidal-delta depositional environment, together with possible tidal-flat areas. The lateral facies change from barrier complex sands of the Arapahoe Sand to the backbarrier deposits of the Beard Creek Member takes place over a broad area beginning near measured section BC3 (Figures 5, 11, 12) at what is now the mouth of Beard Creek.

Beard Creek Member. – Landward of the Newport Sand and Arapahoe Sand Members, shelly, muddy sands with minor silt-clay interbeds crop out along both sides of the Neuse River valley. The Beard Creek Member is up to 6 m thick near the Flanner Beach Recreation Area (measured section FB1, Figure 6) and 4 m thick at Whisk Point (BC1 and BC2, Figure 5), forming a fairly regular blanket-shaped deposit beneath the Talbot geomorphic surface. The Beard Creek could be up to 15 m thick along the axial portion of the ancestral Neuse River paleochannel (see Mixon and Pilkey, 1976, p. 18), but the basal part of these deposits may actually include beds of the Smith Gut Member, as defined herein.

Beard Creek Member exposures at the type locality at Whisk Point consist of four beds, resting conformably on the Smith Gut Member (BC1, BC2; Figure 5): 1) a lower, thick bed consisting of fine sand to muddy sand with pods, stringers, and flat lenses of mollusk shells (consisting overwhelmingly of the valves of *Mulinia lateralis;* Figure 13); overlain by 2) a very shelly, very fine to fine sand packed with *M. lateralis* (Figure 14); grading upward into 3) a thin bed of fine to medium sand, in places with burrows, clay clasts, and *Cyrtopleura* sp. in living positions; capped by 4) a laminated mud with sand interlaminations and lenses, and lacking fossil shells. This sequence of beds records first an environmental mosaic of polyhaline to mesohaline, sandy bottom settings near the seaward margins of a bay or lagoon; followed by shelly, lagoon-floor areas that received little net sediment accumulation owing to by-passing or winnowing when local inlets were active; then sandy lagoonal firm-grounds; and finally the very fine-grained floor of a lagoon center or mainland lagoon-margin bay at the top of the sequence. As the Arapahoe Sand Member outcrop area is approached from the west, Beard Creek Member environ-

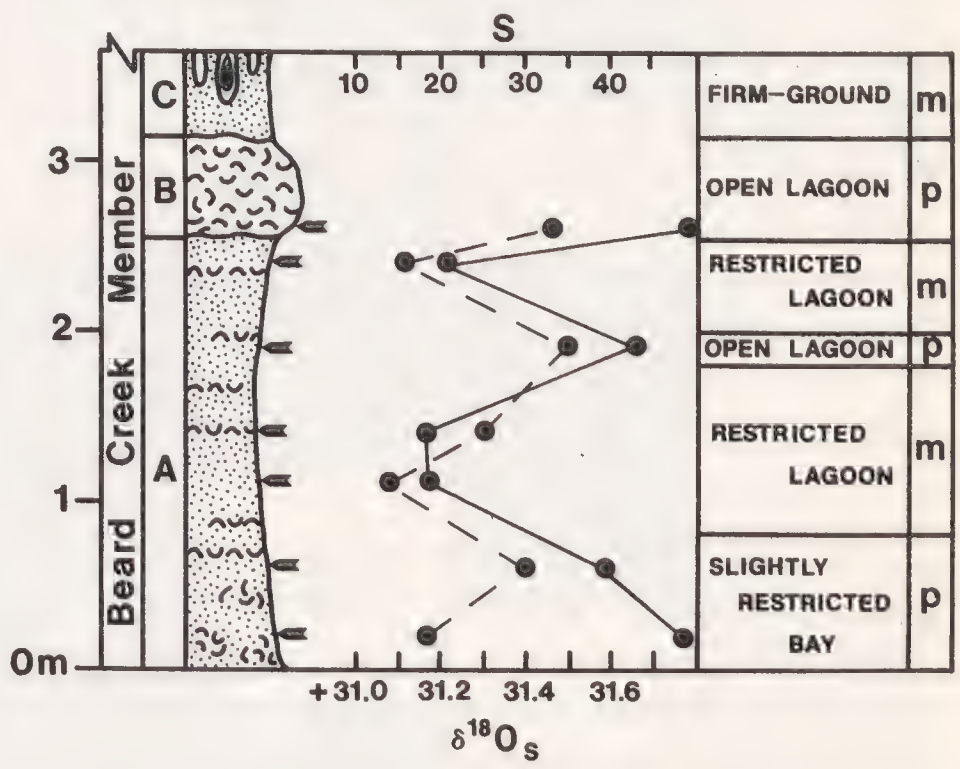

Figure 16. Oxygen-isotope stratigraphy of the Beard Creek Member at Whisk Point, Pamlico County, N.C. Species richness, S (solid line), and $\delta^{18}O_s$ (dashed line) are plotted together against stratigraphic elevation. Fossil associations recognized in bulk samples listed along right side of diagram with inferred average relative salinity (m = mesohaline, p = polyhaline).

ments become largely sandy bottom, outer lagoonal settings with sand derived from sandflats, wash-over fans, and flood tidal-deltas of the adjacent barrier complex (see measured section BC3, Figure 5; also Figures 11, 12).

The Beard Creek Member along the south shore of the Neuse River is generally finer-grained or contains more fine-grained beds, and lacks shelly beds upstream from the Flanner Beach Recreation Area. The stratigraphy of the Flanner Beach Formation at its type locality has been discussed by DuBar and Solliday (1963), and DuBar *et al.* (1974). The exposures at the type locality are now so deeply weathered and overgrown that only the shelly lower portions of the formation are well exposed, and these deposits may form part of the Smith Gut Member rather than the Beard Creek. The exposures at Otter Creek (measured section OC1, Figure 6) have not been previously described, and consist for the most part of two thick beds: 1) a lower sand – silt – sand sequence that is thoroughly bioturbated, with a well-preserved final generation of traces including *Thalassinoides* and *Teichichnus* (Figure 15); overlain by 2) laminated mud with wavy, discontinuous sand interlaminations, lacking trace fossils. This succession of beds represents sandy to silty lagoonal deposits overlain by lagoon-margin muds. A thin, fine sand bed caps the Otter Creek and Flanner Beach Recreation Area sections (Figure 6), and could represent progradational river-estuary deposits.

Depositional Environments – Blounts Bay Area

Hills Point Member. – The lowest bed in the Flanner Beach Formation in the Blounts Bay area of Beaufort County is a laminated silty-clay to clayey-silt with sand lenses and interlaminations, few *Planolites* burrow systems, and carbonized wood fragments. The only body fossils that were collected *in situ* from Flanner Beach equivalents in the Pamlico River valley were molds of *Rangia cuneata,* an oligohaline clam, from the base of the Hills Point Member at its type section (HP1, Figure 7). The Hills Point is about 2.5 m thick and seems to have a blanket-like or tabular geometry. It intertongues with, and grades upward into, the Mauls Point Member, which in places is rather heavily burrow-mottled, suggesting an environmental succession from slightly brackish to possibly mesohaline or even polyhaline conditions. The Hills Point Member probably accumulated as very fine-grained sediments and/or fecal pellets in a well-protected, low salinity lagoonal or river-estuary setting.

Mauls Point Member. – The deposits conformably overlying the Hills Point Member in the bluffs along the margins of Blounts Bay consist of a complex of interbedded sands, muds, and biogenically homogenized units. The Mauls Point Member is about 4 m thick at the type locality (MP1, Figure 7) and also appears to be a blanket-shaped unit. The type section consists of a sequence of five beds: 1) a basal fine to medium sand, with wavy clay interlaminations and small-ripple cross-laminations; 2) a thick bed of interbedded sand and mud; 3) followed by another fine sand bed like the basal layer; 4) a thin mud-sand bed, like the one above the basal sand; and finally, at the top, 5) a thick, burrow-mottled, fine sand with disrupted clay interlaminations. The lower cyclic portion of the sequence seems to represent alternating periods of abundant sand supply and/or higher hydraulic energy levels, and periods of at least intermittently lowered sand supply and/or increased protection from waves and currents. The upper burrow-disrupted bed suggests higher salinity levels allowing larger populations and greater varieties of trace-makers to rework bottom sediments. Mauls Point beds appear to have been deposited in more open lagoonal settings compared with the muds of the Hills Point Member.

Unnamed member. – The Hills Point Member appears to grade eastward into a heavily burrow-mottled, very fine to fine sand containing clay clasts (Figure 7). This unit was probably deposited in the sandy bottom, polyhaline, outer portions of a lagoon. Austin *et al.* (1973) reported abundant molds of bivalves from these deposits. This unit bears the closest resemblance to the typical Flanner Beach Formation deposits of the Neuse River valley of any time-equivalent units examined in the Pamlico valley. It could represent the environmental (facies) equivalent of the lower Beard Creek Member, as exposed at Whisk Point, Pamlico County, and Flanner

Beach Recreation Area, Craven County (Figures 5, 6).

Oxygen-Isotope Stratigraphy

Oxygen-isotope ratio analyses were performed on seven subsamples of *Mulinia lateralis* valves from bulk samples collected from the Beard Creek Member at Whisk Point, Pamlico County (BC1 and BC2; Figures 1, 5). The results are plotted with overall species-richness values of the fossils against stratigraphic elevation in Figure 16, and are expressed in terms of $\delta^{18}O_s$, where

$$\delta^{18}O_s = \left(\frac{^{18}O/^{16}O_{sample}}{^{18}O/^{16}O_{SMOW}} - 1 \right) \times 1000.$$

Deviations are given with respect to the SMOW (Standard Mean Ocean Water) standard (see Anderson and Arthur, 1983).

The $\delta^{18}O$ values from the Beard Creek Member have a mean of +31.29‰ and range between +31.08 and +31.50‰. All samples were rather rich in the heavier isotope, yet the fossils, sediments, and environmental stratigraphic profile of the Beard Creek Member do not suggest unusually high average salinity levels or low growth temperatures for mollusks in original backbarrier habitats (see Miller, 1984). Tan and Hudson (1974) analyzed stable isotopic compositions of mollusks from the Jurassic Great Estuarine Series of Scotland, a marginal marine paleoenvironmental patchwork not unlike the Flanner Beach Formation, and discovered some freshwater and brackish-water mollusks with unaccountably heavy oxygen-isotope values. Lloyd (1964, 1969) suggested that meteoric water precipitated in marsh and mudflat areas marginal to open bodies of water may become enriched in ^{18}O during seasonal dry periods, then are flushed into the adjacent well-mixed waters, with the heavier isotope eventually incorporated into calcareous skeletons of resident invertebrates. Another possibility is that *M.*

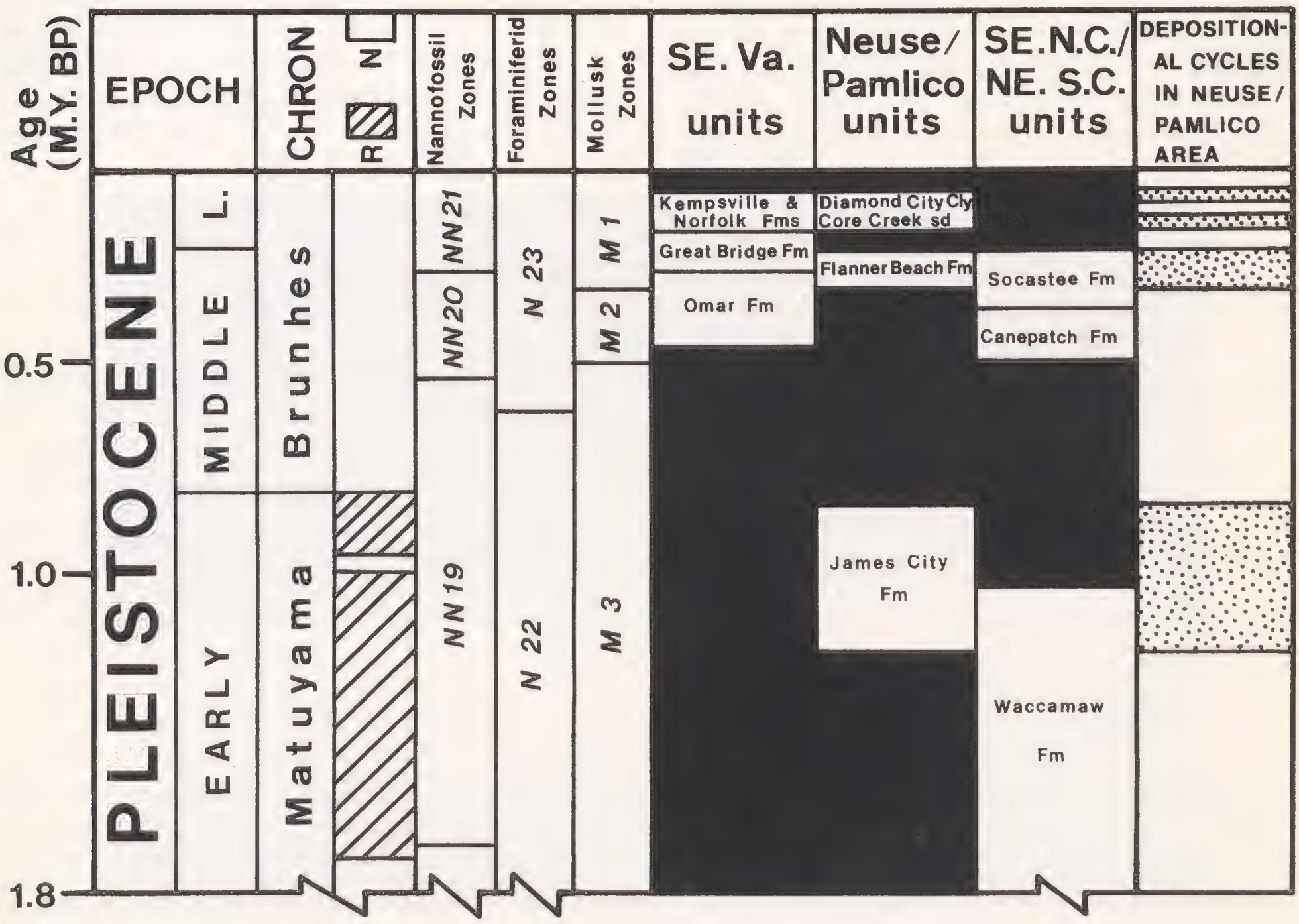

Figure 17. Time-correlation of the Flanner Beach Formation, based on unpublished information provided by Dr. Thomas M. Cronin, U. S. Geological Survey (*in litt.*, 9 May, 1983). Column at right shows depositional cycles in east-central North Carolina.

lateralis may preferentially incorporate the heavier isotope into its skeleton as a result of some sort of "vital effect," or physiologically-mediated non-equilibrium precipitation of $CaCO_3$ as aragonite (see Urey *et al.*, 1951). Perhaps a combination of the flushing of marginal marshes containing waters rich in $\delta^{18}O$, together with the growth of *M. lateralis* shells during spring months in seasonally cool estuarine waters that became mixed with this isotopically heavy runoff, would explain the systematically high $\delta^{18}O_s$ values of carbonate skeletons that grew during a major interglacial high-stand of sea level linked to global warming.

Considering the estuarine paleoenvironmental setting of the Beard Creek Member, oscillations in $\delta^{18}O_s$ probably reflect the effects of dilution of isotopically rather heavy lagoonal waters by lighter freshwater from rivers and streams. Variation of $\delta^{18}O_s$ values with salinity levels in estuaries can be nearly linear (Dodd and Stanton, 1981, figure 3.28), and several studies have successfully employed oxygen-isotope ratio analyses of marginal marine fossils to determine paleosalinities (*e.g.* Tan and Hudson, 1974; Dodd and Stanton, 1975). In most Beard Creek Member samples, highest values of $\delta^{18}O_s$ for *M. lateralis* valves correspond to high values of overall species richness and molluscan diversity, and low values of $\delta^{18}O_s$ are usually matched by high values of molluscan dominance. Therefore, considered in unison with environmental stratigraphic and paleoecologic information, variations in $\delta^{18}O_s$ appear to reflect rhythmic, long-period changes in average salinity levels within the Beard Creek Member (Miller, 1984).

Age and Correlation of the Flanner Beach Formation

The determination of ages and coastwise correlations of Quaternary stratigraphic units in the Atlantic Coastal Plain have

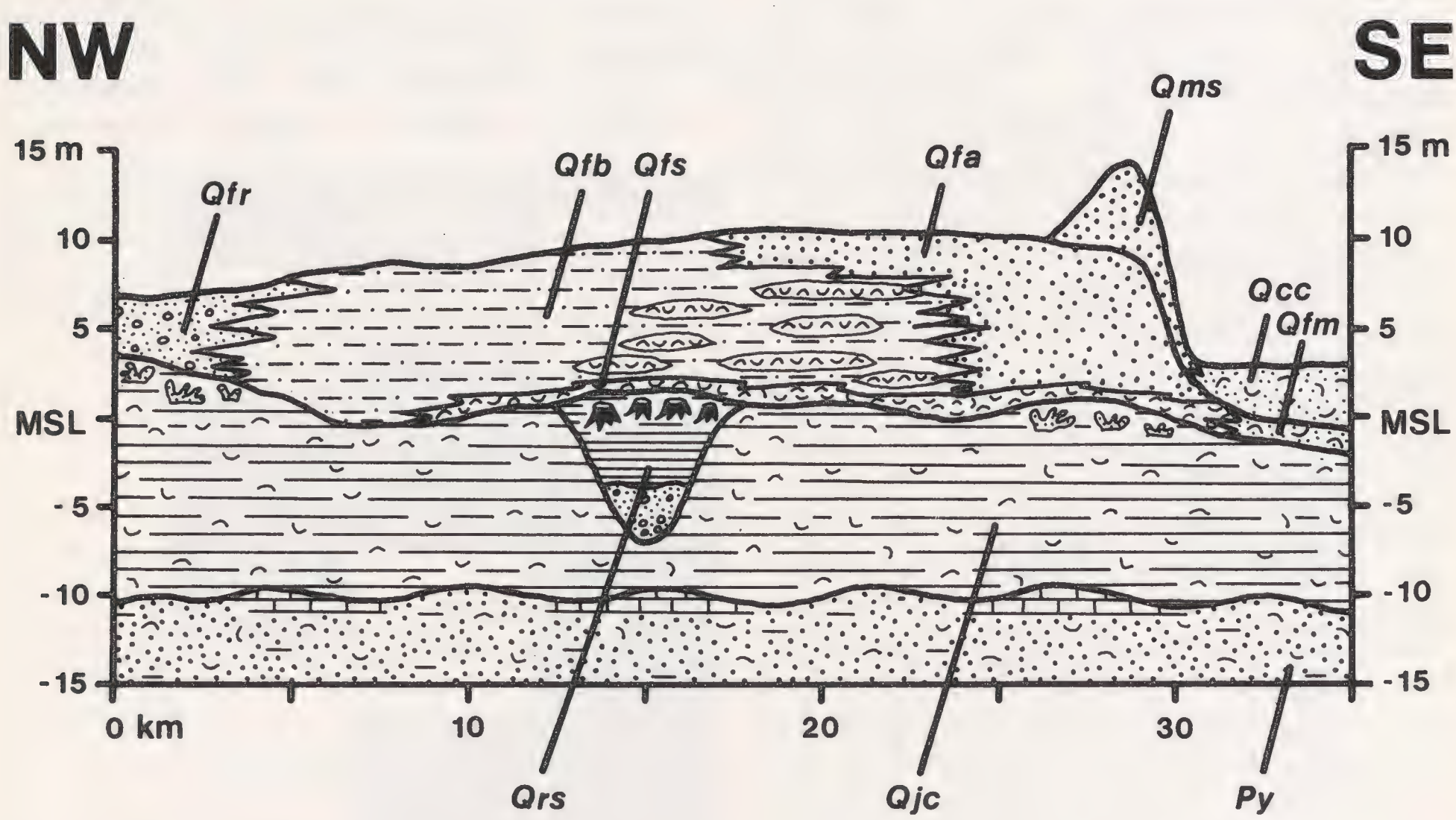

Figure 18. Schematic stratigraphic cross-section down the lower Neuse River from the vicinity of Johnson Point, Craven County, to just east of Minnesott Beach, Pamlico County. Lithostratigraphic units are: *Py*, Pliocene Yorktown Formation; *Qjc*, Early Pleistocene James City Formation; *Qrs*, pre-Flanner Beach river and swamp deposits; *Qfr*, up-valley fluvial equivalents of Middle Pleistocene Flanner Beach Formation; *Qfs*, Smith Gut Member of Flanner Beach Formation; *Qfb*, Beard Creek Member of Flanner Beach Formation; *Qfa*, Arapahoe Sand Member of Flanner Beach Formation; *Qfm*, marine equivalents of Flanner Beach Formation; *Qms*, Late Pleistocene Minnesott sand; *Qcc*, Late Pleistocene Core Creek sand.

been based largely on three properties: 1) elevation and lateral continuity of tops of units forming surface formations [extension of the terrace-formation concept employed by Shattuck (1906), and Stephenson (1912), and many subsequent workers]; 2) vertical relationships of units separated by unconformities (*e.g.* Mansfield, 1928); and 3) identity and relative ages of macroinvertebrate fossil assemblages, mainly mollusks (*e.g.*, Richards' 1936 and 1965 criterion for recognition of "Pamlico Formation" deposits). Newer methods involve the study of smaller areas in greater detail, use of subsurface borings to trace units in the shallow subsurface, and utilization of various paleontologic, geochemical, and geophysical innovations. These innovations include: 1) the use of microfossils, such as foraminiferids and ostracodes, to establish worldwide and intrabasinal correlations (Akers, 1972; Cronin and Hazel, 1976; Cronin, 1980); 2) employment of ostracodes and pollen to reconstruct ancient climates and geographies (*e.g.* Cronin *et al.*, 1981; Whitehead, 1983, and references therein); 3) refinement of molluscan biostratigraphic techniques used to relate onshore Coastal Plain units to a worldwide magnetic time scale (Liddicoat *et al.*, 1979; Liddicoat and Mixon, 1980; Liddicoat *et al.*, 1981); and 5) geochronometric applications of amino acid and radiometric methods (Colquhoun and Blanchard, 1971; Bender, 1973; Belknap *et al.*, 1977; Moslow and Heron, 1979; Blackwelder, 1981a, 1981b; Cronin, 1981; McCartan *et al.*, 1983; Wehmiller and Belknap, 1983). Owing to recent developments in Quaternary oceanic stratigraphy involving the application of stable light-isotope analyses, radiometric and magnetic geochronometry, and biostratigraphic zonations employing planktonic foraminiferids and calcareous nannofossils (see Berggren and van Couvering, 1974; van Donk, 1976), correlations with a more or less continuous and well documented Atlantic Ocean Basin record are now potentially possible for Pleistocene coastal formations.

In the Quaternary section of the Neuse River area, four major transgressive-regressive depositional cycles are preserved as unconformity-bounded sequences. These are, from oldest to youngest: 1) James City Formation (early Pleistocene);

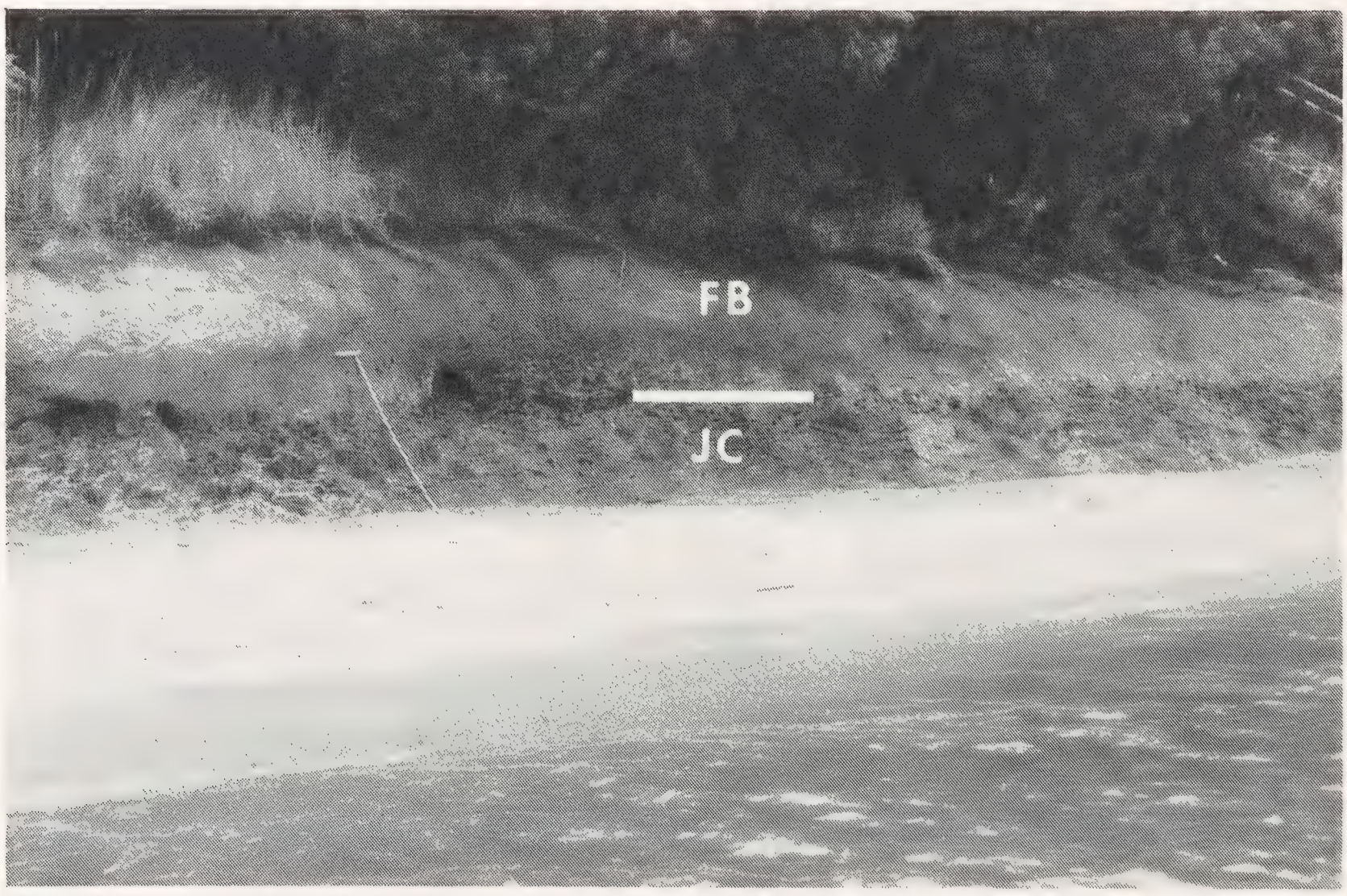

Figure 19. Disconformity separating James City (JC) and Flanner Beach (FB) Formations at private beach 0.7 km southeast of Dam Creek, Craven County, N.C. (measured section DC1 in Figure 6 and Appendix). Ruler is about 1 m long.

2) Flanner Beach Formation (middle Pleistocene); 3) Core Creek sand (late Pleistocene); and Diamond City Clay – Atlantic sand (also late Pleistocene) (DuBar *et al.*, 1974; Mixon and Pilkey, 1976; McCartan *et al.*, 1982). Each depositional cycle should correspond to at least one period of global warming, diminution of continental ice sheets, and rise in world sea-level.

Based on uranium-series and amino acid dating of fossils, the Flanner Beach Formation is now thought to be about 200,000 years old. It is disconformably underlain by an older Pleistocene unit (James City Formation) dating to about 700,000 to 1,000,000 years B.P., and is bordered on the east by younger Pleistocene coastal-margin deposits (Core Creek Sand) dating to about 75,000 to 130,000 years B.P. (McCartan *et al.*, 1982; Thomas M. Cronin, U.S. Geol. Surv., *in litt.*, 9 May, 1983). The Diamond City – Atlantic cycle is apparently Wisconsinian. Liddicoat *et al.* (1979) have shown that the Flanner Beach was deposited during a period of normal magnetic polarity, whereas the underlying James City appears to have been deposited during an earlier period of reversed polarity. They place the Brunhes-Matuyama magnetostratigraphic boundary (dating to about 730,000 years B.P.) in the gap separating the two formations.

If dating of the Flanner Beach is accurate, the unit is correlative with van Donk's (1976) oxygen-isotope stage 7 in the Western Atlantic Basin. In the southeastern Atlantic Coastal Plan, the Flanner Beach Formation is contemporary with the Great Bridge Formation in southeastern Virginia and with the Socastee Formation in southeastern North Carolina – northeastern South Carolina. The formation is within Cronin's (1980, figure 5) ostracode Zone C and Blackwelder's (1981a) mollusk zone M1 (lower Yongesian Substage of the Longian Stage). Figure 17 summarizes the time-correlation of the Flanner Beach and related units as currently understood.

Flanner Beach Depositional Cycle

The sediments and fossils of the Flanner Beach Formation were deposited during a high stand of world sea-level about 200,000 years B.P., corresponding to a major interglacial period reflected in oxygen-isotope stratigraphy of deep oceanic cores (van Donk, 1976, figure 5). Estimated maximum sea-level at this time was +8 (±4.0) m MSL (Cronin *et al.*, 1981). The Flanner Beach can be considered an allostratigraphic unit (see North American Commission on Stratigraphic Nomenclature, 1983, p. 865-867), separated from older (James City) and younger (Core Creek) unconformity-bounded sequences by stratigraphic discontinuities that record low stands of sea-level, which correspond to periods of global cooling, continental glaciation, and coastal emergence (Figures 18, 19).

Internally the Flanner Beach cycle consists of a basal typically thin, pebbly muddy sand (Smith Gut Member) that represents the early and perhaps very rapid inundation of the eastern and southern parts of the Pamlico-Neuse area. This unit contains an environmentally and temporally mixed fossil assemblage that accumulated during the initial submergence of the ancestral Neuse River valley, estuarine lowlands and bordering swamps (*e.g.* cypress-stump bed at Flanner Beach Recreation Area), and seaward areas of low relief (locality SP-1, in Mixon and Pilkey,

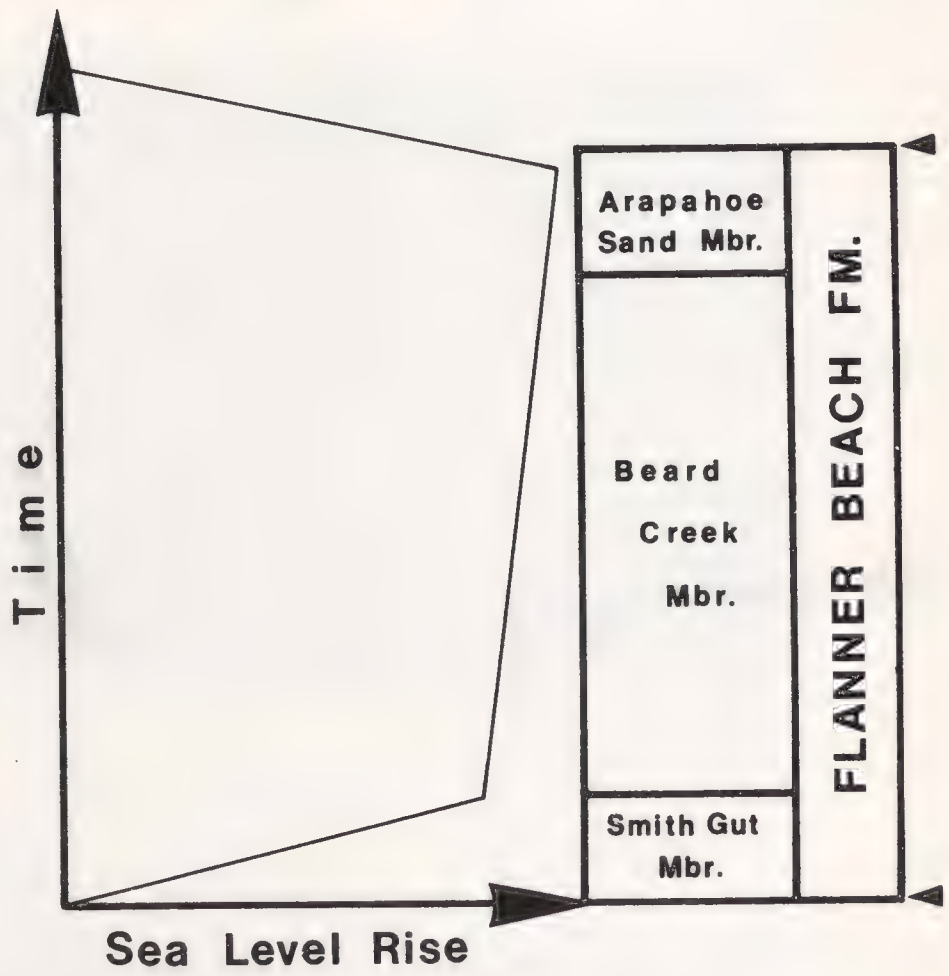

Figure 20. Eustatic model of Flanner Beach Formation as exposed at Whisk Point, Pamlico County, N.C. This is very similar to Hallam's (1981, p. 124) eustatic model E, with rapid rise and lowering of sea level interrupted by a prolonged period of very gradual rise in sea level.

1976, Plate 1). Following the initial flooding of the Neuse River area it appears that barrier islands, possibly prograding southward from a headland in the vicinity of the Pamlico River, began the isolation of a coastal compartment that was to become the depositional center for shelly, muddy sand of the Beard Creek Member to the south, and for sediments of the Hills Point and Mauls Point Members to the north. Communication with the adjacent ocean through migrating inlets was more open in the southern portion of this estuarine basin, as shown by stratigraphic evidence and presence of polyhaline fossil associations (Miller, 1984). The gap between the Arapahoe Sand and Newport Sand outcrop areas (Mixon and Pilkey, 1976, Plate 1) may indicate the former position of a large bay-mouth that originally separated these two barrier segments. This bay-mouth would have allowed open circulation between a backbarrier bay or sound and the adjacent Atlantic Ocean. The Flanner Beach Formation sediments cropping out in the Pamlico River valley would have been deposited in a shallow, protected part of the basin farthest from the bay mouth and probably close to the mouth of the ancestral Tar River, as shown by facies relationships, lithologies, and the presence of few trace fossils and oligohaline clams. Within the Beard Creek Member, a succession of beds with mesohaline to polyhaline fossil associations, with varying $\delta^{18}O$ values (Figure 16), records changes in circulation patterns within the basin caused by modifications in coastal geomorphology (establishment of the Arapahoe barrier, opening and closing of inlets, in-filling of the basin). This is a second-order cycle developed within the primary glacio-eustatic depositional cycle represented by the entire formation.

After deposition of the Smith Gut Member, the rate of sea-level rise apparently decreased, as during the ongoing post-Wisconsinian eustatic rise of sea-level (see Milliman and Emery, 1968; Bloom, 1970). During this interval the Arapahoe-Newport barrier was constructed; inlet formation and migration, and backbarrier basin in-filling were probably the dominant depositional processes. Landward building of washover fans and development of extensive flood tidal-deltas helped to complete the filling of the Flanner Beach estuarine basin (*cf.* Moslow and Heron, 1979, p. 229-233), as indicated by the facies onlap of Arapahoe Sand onto Beard Creek Member deposits at Whisk Point, Pamlico County (Figure 5, 11). At about the same time, the Newport barrier segment to the south was prograding seaward, as indicated by the development of curved, convex-landward beach ridges in Carteret County. Laminated mud beds, which lack fossils or burrows, occurring near the top of the Beard Creek Member at Otter Creek and Flanner Beach Recreation Area, Craven County, and at Hills Point, Beaufort County, in the top of the Mauls Point Member (Figures 6, 7), could represent the final stage of in-filling of the backbarrier basin by fine-grained lacustrine (?) or river-estuary sediments. A rapid lowering of sea-level left the Flanner Beach Formation emergent, and susceptible to fluvial erosion by down-cutting of river channels and to pedogenic alteration as the marine shoreline retreated across the continental shelf to the east (see Figure 20).

VII. FUTURE WORK ON THE FLANNER BEACH FORMATION AND RELATED UNITS

The U. S. Geological Survey continues to show a great amount of interest in the Flanner Beach and related units in the Atlantic Coastal Plain. New reports on paleoclimatology and sea-level history of coastal formations (Thomas M. Cronin), and on new uranium-series dates from this area (Barney J. Szabo) are being prepared. The paleoecologic findings from my study of Flanner Beach Formation fossils will be published within about a year. The present report is intended to provide an update on the stratigraphy of the Flanner Beach Formation and indicates that much is now known about the geologic history of this interesting unit.

In the future, researchers might consider examining the following unsolved problems:

1) Can marine equivalents of the Flanner Beach be recognized east of the Suffolk Scarp, and what is the nature and age of these deposits?

2) Few studies have attempted to relate Quaternary, up-valley fluvial units in the Atlantic Coastal Plain to the better known estuarine and marine deposits of the outer Coastal Plain (see Miller, 1979). Researchers interested in fluvial processes and landforms of coastal rivers can rightly regard this as a completely open field for study in North Carolina.

3) More needs to be known about the latest Pleistocene history of the Pamlico-Neuse area. Units such as the "Atlantic sand" of Mixon and Pilkey (1976) need to be investigated in more detail, and related to older and younger depositional cycles.

4) Is there a distinct depositional cycle represented by the "intermediate terrace" lying between the Pinetown and Union Chapel scarps, with a surface elevation of about +10 m MSL, described briefly by Mixon and Pilkey (1976, p. 36) from the Albermarle Sound – Pamlico River interfluvial plain? Or, alternatively, is this surface related to emplacement of the Flanner Beach Formation or Core Creek Sand?

5) Is the Walterboro Scarp the western boundary of Flanner Beach estuarine beds, or do Flanner Beach deposits extend beneath the scarp to the west, with the scarp representing a temporary stillstand of a retreating Flanner Beach sea (see Daniels *et al.*, 1972, figure 3 and p. 16)?

6) To my knowledge, stable light isotopes have not been used to any great extent to characterize paleotemperatures and paleosalinities in the outer Coastal Plain of North Carolina. My use of fluctuations in $\delta^{18}O$ values in the Beard Creek Member to corroborate faunal inferences of local changes in relative salinity levels during the development of the Flanner Beach estuarine basin has convinced me of the great potential that this approach holds. With careful paleoecologic studies, isotope-ratio analyses should yield valuable data that will enable more accurate, detailed reconstructions of paleoenvironments.

7) Although much has been written about occurrences of macroinvertebrate fossils in the Neuse River area, little useful paleoecologic information has ever been published. The units in this area are no less interesting paleontologically because they are so geologically young; the fauna contained in the James City, Flanner Beach, and Core Creek sequences can be very rich in species and/or numbers of individuals and records an extraordinary history of changing climates and sea-levels in the region. The study of the faunal and floral history of these Quaternary units has just begun.

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IX. APPENDIX

Measured sections in the Flanner Beach Formation in its type area (Neuse River valley) and in the Blounts Bay area (Pamlico River valley), eastern North Carolina.

All sections measured and described in Summer, 1982. Measured section numbers and bed letters are keyed to the stratigraphic panel diagrams (Figures 5, 6, 7, 8). Location of sections is shown in Figure 1, and described in detail at the beginning of each entry below. *Section SG1 is the type section of the Smith Gut Member, section HP1 is the type section of the Hills Point Member, and section MP1 is the type section of the Mauls Point Member.*

NORTH SHORE OF NEUSE RIVER, FIGURE 5

I. *MEASURED SECTION BC1*

Bluffs 0.6 km northwest of center of mouth of Beard Creek, at end of jeep trail about 0.3 km upstream from Whisk Point; north shore Neuse River, Pamlico County, N. C.; southeast corner Upper Broad Creek 7.5 ′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

F. Soil . . . . . 1.8 m

E. Sand, fine, well-sorted, angular to subangular, loose, light pinkish-gray (5 YR 9/1); few slightly indurated muddy sand interlaminations; traces of heavy minerals and mica; no fossils observed; heavily burrow-mottled (?) gradational contact with top of bed D . . 1.7

BEARD CREEK MEMBER

D. Mud with sand interlaminations and lenses; sticky, slightly indurated; dark greenish-gray (5 G 4/1) with moderate brown (5 R 4/4 – 3/4) color mottles; sand partings up to 10 mm thick near top and bottom, 2 to 3 mm thick near middle; no fossils observed; top grades into unit E, bottom intertongues with unit C 1.6

C. Sand, fine, moderately sorted, subangular, moderately indurated; dark bluish-gray (5B 4/1); top heavily burrowed, with small curved-cylindrical burrows about 5 mm in diameter and larger straight-cylindrical burrows 4 to 5 cm in diameter; some larger burrows contain *Cyrtopleura* sp. in living positions, molds of other bivalves near bottom; clay clasts (= disrupted clay interlaminations) scattered throughout; top intertongues with unit D, bottom undulatory and grades into unit B 0.5

B. Shelly sand; sand very fine to fine, poorly sorted, subangular to angular, trace of heavy minerals; dark greenish-gray (5 G 3/1); abundant *Mulinia lateralis, Ensis directus, Polinices duplicatus, Busycon* spp., bivalves mostly disarticulated and randomly oriented; slightly muddy in places; top and bottom undulatory and gradational with units C and A 0.6

A. Sand, fine, subangular to subround, moderately sorted, slightly indurated; medium bluish-gray (5B 5/1); discontinuous clay interlaminations up to 2 cm thick with burrow perforations; shelly sand lenses up to 5 cm thick with abundant *Mulinia lateralis*, surrounded by sparsely fossiliferous, bioturbated sand; bivalve shells oriented randomly near bottom and with convex-sides-up near top; trace of heavy minerals; top grades into unit B and base is covered . . . . . 1.4+

Covered interval 1.2

Total: 8.8 m

II. *MEASURED SECTION BC2*

Bluffs about 0.3 km southeast of BC1 and 0.4 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore Neuse River, Pamlico County, N.C.; southwest corner Arapahoe 7.5′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

F. Soil . . . . . 1.2 m

E. Sand, fine, well-sorted, subangular, loose; light pinkish-gray (5 YR 9/1); faint trough cross-laminations and few clay interlaminations near base; trace of heavy minerals; no fossils observed; top gradational with unit F, bottom intertongues with unit D 1.2

BEARD CREEK MEMBER

D. Mud with sand interlaminations and lenses; sticky, slightly indurated; dark greenish-gray (5 G 4/1) with moderate brown (5 YR 4/4) color mottles; sand interlaminations more

common, thicker near top and bottom; no fossils observed; top and bottom intertongue with units C and E 1.1

C. Sand, fine to medium, moderately sorted, subangular to angular, moderately indurated; dark bluish-gray (5 B 4/1); slightly muddy, structureless (bioturbated?); no fossils observed; top intertongues with unit D, bottom undulatory and grades into B 0.4

B. Shelly sand; sand very fine to fine, poorly sorted, subangular to angular, trace of heavy minerals; dark greenish-gray (5 G 3/1); abundant *Mulinia lateralis, Ensis directus, Polinices duplicatus, Busycon* spp., bivalves mostly disarticulated and randomly oriented; slightly muddy in places; top and bottom undulatory and gradational with units C and A 0.6

A. Sand, fine, well-sorted, subangular to angular, slightly indurated; medium bluish-gray (5 B 5/1); clay clasts and burrow systems referrable to *Thalassinoides;* slightly muddy near base; shelly lenses near top and irregularly shaped pods near bottom with abundant *Mulinia lateralis,* surrounded by sparsely fossiliferous bioturbated sand; bivalve shells in lenses near top of unit frequently oriented convex-sides-up, more often randomly oriented near base of unit; trace of heavy minerals; top grades into unit B, bottom not exposed . . . . . 2.4+

Total: 6.9 m

III. *MEASURED SECTION BC3*

Bluffs about 0.1 km east of BC2 and 0.3 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore Neuse River, Pamlico County, N. C.; southwest corner Arapahoe 7.5′ quadrangle.

FLANNER BEACH FORMATION

BEARD CREEK MEMBER

F. Soil . . . . . 0.2 m

E. Mud with sand interlaminations and lenses, pedogenically altered and moderately indurated; dark yellowish-orange (10 YR 6/6) to grayish orange (10 YR 7/4); no fossils observed; top grades into unit F, bottom grades abruptly into unit D 0.7

D. Sand, fine to very fine, moderately sorted, subangular, loose with slightly indurated limonitic layers, very pale orange (10 YR 8/2), limonite-cemented zones light brown (5 YR 5/6); ripple cross-laminated, few clay flasers in ripple troughs, clay interlaminations near base 9 to 14 cm thick; no fossils observed; top and bottom grade abruptly into units E and C 1.7

C. Interlaminated clay and sand; clay dark greenish-gray (5 G 4/1), sand same as in unit D; no fossils observed; top and bottom grade abruptly into units D and B 0.2

B. Sand, fine, moderately to well sorted, subangular, slightly indurated; light olive-gray (5 Y 6/1) in upper two-thirds changing to dark bluish-gray (5 B 4/1) in lower third; heavily bioturbated, clay clasts and biogenically distrupted clay laminations; few bivalve molds near base; becomes slightly silty near bottom; top grades abruptly into unit C, bottom grades gradually into unit A 1.2

SMITH GUT MEMBER

A. Shelly sand; sand very fine to fine, poorly sorted, subround, moderately indurated; dark greenish-gray (5 G 4/1); silty and contains abundant shells of *Mulinia lateralis,* some of which are oriented convex-sides-up but most are arranged randomly in bed; contains some reworked James City Formation fossils and forms limonite-cemented ledge at toe of bluff, so could be mistaken for top of older formation; top grades into unit B, bottom not exposed . . . . . 0.6+

Total: 4.6 m

IV. *MEASURED SECTION SG1*

Bluffs 3.4 km southeast of center of mouth of Beard Creek and 0.3 km northwest of Smith Gut, north shore of Neuse River, Pamlico County, N. C.; northwest part of Cherry Point 7.5′ quadrangle. *Type section of Smith Gut Member.*

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

E. Soil . . . . . 1.0 m

D. Sand, fine to medium, moderately sorted, subangular to angular, loose; yellowish-gray (5 Y 8/1); trough cross-laminated, with occasional wavy clay interlaminations and clay clasts; heavy mineral content and size of clay clasts increase toward base; no fossils observed; contact with unit E gradational, contact with unit C wavy, sharp 2.6

C. Interbedded sandy mud and sand; mud layers laminated to massive, soft, pale red (10 R 6/2) to pale yellowish brown (10 YR 6/2); sand fine, well sorted, subround to subangular, loose, very pale orange (10 YR 8/2); sand interbeds contain burrows, discontinuous

to continuous pebble layers (quartz pebbles up to 1 cm in longest dimension), clay clasts, and ripple cross-laminations; no fossils observed; top contact sharp with unit D, bottom undulatory, grading into unit B 0.8

B. Sand; near top – medium, moderately sorted, subround to subangular, loose, white (N9); near bottom – medium to coarse, poorly sorted, round to subangular, loose, dark yellowish-orange (10 YR 6/6); clay interlaminations throughout, with ripple cross-laminations and clay drapes in upper part and trough cross-laminations in lower part; no fossils observed; top grades into unit C, bottom grades abruptly into unit A 3.0

SMITH GUT MEMBER

A. Muddy sand with shells; upper 3 cm sand-mud mixture with sand fine to medium, subround to subangular, poorly sorted as a shole, slightly indurated, light olive-brown (5 Y 5/6); bottom part slightly less muddy with abundant shells of *Mulinia lateralis*, slightly indurated, dark greenish-gray (5 GY 4/1); top grades abruptly into unit B, base not exposed . . . . . 0.5+

Total: 7.9 m

SOUTH SHORE OF NEUSE RIVER, FIGURE 6

V. *MEASURED SECTION OC1*

Bluffs 0.3 km southeast of center of mouth of Otter Creek and 0.7 km northwest of Flanner Beach Recreation Area, south shore Neuse River, Craven County, N. C.; north-central part of Havelock 7.5′ quadrangle.

FLANNER BEACH FORMATION

BEARD CREEK MEMBER

E. Soil . . . . . 0.9 m

D. Sand, fine, poorly sorted, subangular to angular, moderately indurated, grayish-orange (10 YR 7/4); pedogenically altered, apparently structureless, slightly silty; no fossils observed; top and bottom grade into units E and C 0.4

C. Mud, slightly sandy, light gray (N7); with discontinuous wavy sand interlaminations up to 4 cm thick near top and bottom; sand very fine to fine, moderately sorted, subround to subangular, yellowish gray (5 Y 8/1); no fossils observed; top and bottom grade into units D and B 1.2

B. Sand and silt; top 1 m is sand, very fine to fine, moderately sorted, subangular, very light gray (N8) to white (N9), thoroughly burrow-mottled, with discontinuous clay interlaminations and a few clay clasts; middle 1.2 m is coarse silt to very fine sand, light gray (N7), burrow-mottled; bottom 0.8 m is sand, fine, moderately sorted, subangular, light gray (N7), with clay clasts and burrows; lastest generation of burrow systems include *Thalassinoides* and *Teichichnus;* unit slightly to moderately indurated; no skeletal fossils observed; top grades into unit C, bottom grades abruptly into unit A 3.0

SMITH GUT MEMBER (?)

A. Muddy sandstone to sandy mudstone; laminated to thickly bedded, limonite-cemented, light brown (5 YR 5/6); indurated, ledge-forming unit poorly exposed; no fossils observed; top grades abruptly into unit B, base not exposed . . . . . 0.5+

Total: 6.0

VI. *MEASURED SECTION FB1*

Bluffs 0.5 km southeast of Flanner Beach Recreation Area, south shore Neuse River, Craven County, N. C.; Havelock 7.5′ quadrangle. *This is type locality of Flanner Beach Formation of DuBar and Solliday (1963).*

FLANNER BEACH FORMATION

BEACH CREEK MEMBER

I. Soil . . . . . 1.0 m

H. Sand, fine, moderately to well sorted, subangular to angular, slightly indurated; very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4) with dark yellowish-orange (10 YR 6/6) bands; ripple cross-laminated, faint larger-scale cross-stratification; no fossils observed; top and bottom grade into units I and G 0.7

G. Interbedded mud and sand; mud layers up to 5 cm thick, sticky, medium gray (N5), with discontinuous interlaminations of coarse silt; sand interbeds and flat lenses up to 2 cm thick, with low-angle cross-laminations; sand very fine to fine, moderately sorted, subangular to angular, dark yellowish-orange (10 YR 6/6); no fossils observed; top and bottom grade into units H and F 0.8

F. Mud, sticky, slightly sandy; medium gray (N5); few sand interlaminations; sand very fine, moderately sorted, subangular to angular, very light gray (N8); no fossils observed; top and bottom grade into units G and E 0.4

E. Sand, fine to medium, moderately to poorly sorted, subangular to angular, slightly indurated; light olive gray (5 Y 6/1); heavily burrow-mottled with light brown (5 YR 5/6) color mottles coinciding with burrows; slightly muddy near top, disrupted laminations to thin beds of sand throughout; no skeletal fossils observed; top grades into unit F, bottom sharp, but conformable with unit D 1.5

D. Shell-mold bed; sand, silty, fine to medium, poorly sorted, subangular, limonite-cemented and moderately indurated; light brown (5 YR 5/6) with very light gray (N8) color mottles; abundant molds of bivalves throughout; top and bottom sharp, but conformable with units E and C 0.3

C. Muddy sand; sand fine, poorly sorted, subangular; light olive gray (5 Y 6/1); heavily burrow-mottled, some disrupted clay interlaminations; slightly indurated; no skeletal fossils observed; top sharp, conformable with unit D, bottom undulatory, gradational with B . 1.4

SMITH GUT MEMBER (?)

B. Shelly sand; sand medium, well sorted, subround to subangular, shelly in bottom two-thirds, slightly to moderately indurated; olive gray (5 Y 4/1) where shelly, dark yellowish-orange (10 YR 6/6) in upper unfossiliferous portion of bed; faintly cross-laminated, with sand and clay clasts; abundant shells of *Mulinia lateralis* randomly oriented, some shells of *Dinocardium robustum* near base oriented convex-sides-up; becomes muddy sand upstream, laterally along the outcrop face; top wavy, grading into C, bottom is disconformable contact with unit A 0.3

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sandy mud; medium gray (N5) to medium dark gray (N4) with light brown (5 YR 5/6) color mottles associated with root channelways; some fossil trunks and roots of trees in living positions, larger root channelways just below contact filled with sand from above; top also with sand-filled burrow systems; moderately indurated; top disconformable contact with unit B, base not exposed . . . . . 1.4+

Total: 7.8 m

VII. *MEASURED SECTION DC1*

Low banks 0.7 km southeast of Dam Creek and 2.2 km southeast of Flanner Beach Recreation Area, at private beach on south shore Neuse River, Craven County, N. C.; Havelock 7.5′ quadrangle.

FLANNER BEACH FORMATION

Covered interval . . . . . approx. 2.0 m

C. Muddy sand to sandy mud; bluish-gray (5 B 4/1); fine, moderately sorted, subangular to angular; burrows near top, clay clasts throughout; occasional molds of bivalves; slightly indurated; top not exposed, bottom grades into B 0.3

B. Shelly muddy sand; same as unit C but with abundant shells of *Mulinia lateralis,* mostly randomly oriented; *Dinocardium robustum* shells oriented with convex-sides-up near base; top grades into unit C, bottom is disconformable contact with unit A 0.5

UNCONFORMITY

JAMES CITY FORMATION

A. Mud; medium bluish-gray (5 B 5/1); slightly shelly with *Nuculana acuta* common, *Septastrea* sp. coral heads up to 40 cm in diameter near base of unit apparently in living positions; burrows or borings near top filled with sand and shells from unit B; massive, moderately indurated; top is disconformable with unit B, base not exposed . . . . . 1.0+

Total: 3.8 m

VIII. *MEASURED SECTION PC1*

Bluffs just east of beach at Pine Cliff Recreation Area, 0.2 km east of end of unpaved access road, at Cherry Point, south shore Neuse River, Craven County, N. C.; Cherry Point 7.5′ quadrangle.

FLANNER BEACH FORMATION

ARAPAHOE SAND MEMBER

C. Soil . . . . . 1.3 m

B. Interbedded sand and muddy sand; sand fine to medium, moderately sorted, subangular, loose, pale yellowish-orange (10 YR 7/2) to very pale orange (10 YR 7/4) near top to light pinkish-gray (5 YR 9/1) near base of unit; muddy sand slightly indurated, limonitic, pale yellowish-brown (10 YR 6/2) to light brown (5 YR 5/6); major bedding units nearly horizontal in top one-third, inclined eastward (up to 28°) in lower two-thirds of unit; sand

interbeds contain trough and planar cross-laminations, clay clasts and rare discontinuous interlaminations; abundant bivalve (?) burrows 5 to 10 mm in diameter that extend from bottoms of each layer into top of the subjacent layers; base of unit with discontinuous muddy sand lens, light olive gray (5 Y 6/1), non-limonitic; no skeletal fossils observed; top and bottom gradational with units C and A 2.5

A. Sand, fine to coarse, moderately to poorly sorted, subround to subangular, loose; very light gray (N8) to pale yellowish-orange (10 YR 8/6); large wedge-shaped cross-stratification sets with internal laminations dipping gently (5° to 10°) westward and more steeply (up to 35°) eastward; few burrows, clay clasts, limonitic bands, and pebbly laminations with flat quartz pebbles up to 1 cm in longest dimension; no skeletal fossils observed; top grades into unit B, bottom not exposed . . . . . 0.8+

Total: 4.6 m

SOUTH SHORE OF PAMLICO RIVER, FIGURE 7

IX. *MEASURED SECTION HP1*

Bluffs 0.2 km upstream from Camp Hardee and about 1.2 km west of Hills Point, south shore Pamlico River, Beaufort County, N. C.; Blounts Bay 7.5′ quadrangle. *Type section of Hills Point Member.*

FLANNER BEACH FORMATION

MAULS POINT MEMBER

F. Soil . . . . . 1.0 m

E. Interlaminated mud and sandy silt; mud medium gray (N5), silt very light gray (N8); top half pedogenically altered; slightly indurated; no fossils observed; top and bottom grade into units F and D 0.5

D. Silty sand; sand very fine (N8); heavily burrow-mottled in top half, few clay interlaminations in bottom half; no skeletal fossils observed; top grades into unit E, bottom grades very gradually into unit C 0.8

C. Sand, fine to medium, poorly sorted, subround to subangular, loose; very light gray (N8); clay interlaminations throughout but more common near bottom, medium light gray (N6), in places disrupted by burrows; faint ripple cross-laminations in sand; burrows 5 mm in diameter referrable to *Planolites*, few larger horizontal burrows up to 25 mm in diameter; no skeletal fossils observed; top and bottom very gradational to units D and B 1.4

HILLS POINT MEMBER

B. Mud; clay-silt mixture becoming clayeyer near base, medium dark gray (N4); with sand lenses and interlaminations, sand very fine, moderately sorted, subangular to angular, light olive gray (5 Y 6/1); interlaminations wavy, discontinuous, in bundles up to 5 cm thick, along with few laterally continuous bundles, both types more common near top; some interlaminations disrupted by burrows 5 to 20 mm in diameter; brownish black (5 YR 2/1) carbonized wood fragments up to 2 cm in longest dimension scattered throughout clay in basal 1 m; bottom marked by limonite-cemented mudstone layer, 1 to 3 cm thick, moderate brown (5 YR 3/4) to light brown (5 YR 5/6), with sparse molds of *Rangia cuneata;* unit sticky, soft except for indurated limonitic layer; top grades into unit C, bottom is disconformable contact with unit A 2.5

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sand, fine to medium, moderately to poorly sorted, subround to subangular, slightly indurated; pinkish gray (5 YR 8/1) to yellowish gray (5 Y 8/1) with light brown (5 YR 5/6) color mottles; color mottles coincide with root channelways, otherwise massive; slightly muddy; no skeletal fossils observed; top is disconformable contact with unit B, base not exposed . . . . . 1.7+

Total: 7.9 m

X. *MEASURED SECTION MP1*

Bluffs 1.2 km southwest of Mauls Point along southeastern shore of Blounts Bay, south shore Pamlico River, Beaufort County, N. C.; central part of Blounts Bay 7.5′ quadrangle. *Type section of Mauls Point Member.*

FLANNER BEACH FORMATION

MAULS POINT MEMBER

H. Soil . . . . . 1.3 m

G. Sand, fine, well sorted, subround to subangular, loose; very light gray (N8); discontinuous mud interlaminations throughout, medium light gray (N6), up to 5 mm thick, becoming more numerous and thicker toward base, generally disrupted by burrows that coincide with dark yellowish-orange (10 YR 6/6) color mottles; no skeletal fossils observed; top and bottom grade into units H and F 2.1

F. Interlaminated mud and sand; mud and sand same as in unit G, but with much less bioturbated, wavy parallel layers; no skeletal fossils observed; top grades into unit G, bottom grades abruptly into unit E 0.2

E. Sand, fine, moderately to well-sorted, subangular, loose; very light gray (N8); with discontinuous clay interlaminations and clay clasts throughout; no fossils observed; top and bottom grade abruptly into units F and D 0.5

D. Interbedded sand and mud; sand fine, well sorted, subangular, loose, white (N9); mud medium light gray (N6), sticky, slightly sandy; sand layers up to 5 cm thick, mud layers up to 4 cm thick; no fossils observed; top and bottom grade abruptly into units E and C . 0.9

C. Sand, fine to medium, moderately sorted, subangular, loose; very light gray (N8); occasional discontinuous wavy clay interlaminations up to 5 mm thick, and ripple cross-laminations accented by heavy mineral-rich laminations; no fossils observed; top grades abruptly into unit D, bottom intertongues with unit B 0.8

HILLS POINT MEMBER

B. Mud, sticky, laminated, medium bluish-gray (5 B 5/1); with sand interbeds and interlaminations–sand very fine to fine, moderately sorted, subangular, slightly micaceous, same color as mud; interbeds with rippled tops and flat bottoms, interlaminations wavy-parallel, both becoming less common toward base; few *Planolites*-like horizontal burrows 1 to 2 cm in diameter, and brownish-black (5 YR 2/1) carbonized wood fragments in discontinuous laminations up to 2 mm thick; top intertongues with unit C, bottom is disconformable contact with unit A 2.7

UNCONFORMITY

PRE-FLANNER BEACH FLUVIAL DEPOSITS

A. Sandstone, medium to coarse, poorly sorted, hematite-cemented, indurated but friable; grayish-brown (5 YR 3/2); no structures observed at outcrop, but boulders of same lithology just offshore are trough cross-laminated with pebbly layers (graded?); no fossils observed; top is disconformable with unit B, base not exposed . . . . . 0.3+

Total: 8.8 m

XI. *MEASURED SECTION TP1*

Bluffs 0.8 km northwest of Tripp Point and 0.7 km southeast of center of mouth of Nevil Creek, south shore Pamlico River, Beaufort County, N. C.; east-central part of Blounts Bay 7.5′quadrangle.

FLANNER BEACH FORMATION

MAULS POINT MEMBER (?)

D. Soil . . . . . 1.4 m

C. Sand, fine to medium, moderately to well-sorted, subangular, loose; very pale orange (10 YR 8/2) to grayish orange (10 YR 7/4); low-angle cross-laminations in wedge-shaped (?) sets, some faint horizontal sand laminations near base, and wavy-parallel clay interlaminations in bundles up to 4 cm thick; no fossils observed; top and bottom grade into units D and B 2.5

B. Mud, sticky, laminated, medium dark gray (N4); with wavy discontinuous sand interlaminations; sand very fine to fine, moderately sorted, subangular, very light gray (N8); some interlaminations disrupted by burrows; no skeletal fossils; top and bottom grade into units C and A 1.1

UNNAMED MEMBER

A. Sand, very fine to fine, moderately to poorly sorted, subround, very slightly indurated to loose; olive gray (5 Y 4/1); slightly muddy, with clay clasts (= disrupted clay layers); unit heavily burrow-mottled, with last generation of structures including many curved cylindrical sand-filled burrows 5 to 10 mm in diameter; no skeletal fossils observed; unit poorly exposed, with top grading into unit B and base covered by talus . . . . . 1.6+

Covered interval . . . . . approx. 2.5

Total: 9.1 m

A NEW SPECIES OF *GOULDIA* (MOLLUSCA: BIVALVIA) FROM THE PLEISTOCENE OF EASTERN NORTH CAROLINA

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The small venerid bivalve *Gouldia* is represented by many look-alike species from both modern and fossil Cenozoic marine environments. In the western Atlantic-Caribbean region the genus consists of species that feature either an exterior surface sculpture of fine radial costae crossing the concentric growth bands on the anterior and posterior edges of valves, or a more uniformly reticulate pattern over the whole of valve exteriors. All of these forms are assigned to the subgenus *Gouldia,* with the best known and most widely distributed species being *Gouldia (Gouldia) cerina* (C.B. Adams, 1845), the type of the genus.

Owing to the discovery of a rare new species described herein, in the middle Pleistocene Flanner Beach Formation, eastern North Carolina (Fig. 1), a second supraspecific subdivision of *Gouldia* is here recognized. The members of this subgenus have a surface ornamentation of coarse, flat costae that cross the concentric bands along the anterior and posterior ends of the valves, in contrast to the typical finely costate to reticulate surface design of most species of *Gouldia.*

The purpose of this note is to describe the new species from the Flanner Beach Formation, and to comment on its possible evolutionary and biostratigraphic significance. The general stratigraphy, geologic age and time-correlation, and paleoenvironmental contexts of the formation have been described by DuBar and Solliday (1963), Mixon and Pilkey (1976), McCartan *et al.* (1982), and Miller (this volume). All specimens have been deposited in the Academy of Natural Sciences of Philadelphia, Pennsylvania (ANSP).

Family VENERIDAE Rafinesque, 1815
Subfamily CIRCINAE Dall, 1896
Genus GOULDIA C.B. Adams, 1847
Subgenus PARAGOULDIA, new subgenus

Description: Species of *Gouldia* with conspicuous broad, flat, radial costae adjacent to anterior and posterior margins of valve exteriors; interior morphology typical for the genus.

Type species: *Gouldia (Paragouldia) platycostata* n. sp.

GOULDIA (PARAGOULDIA) PLATYCOSTATA
W. Miller, III, new species
Fig. 2

Description: Shell small, largest valves measuring only 8 mm in length by 7 mm in height, subtrigonal to trigonal, becoming more inflated and equidimensional in adult stages; anterior and posterior ends rounded, with the posterior slightly more so than the anterior, the latter with a weakly developed shoulder beneath the umbones; beaks pronounced and rather high in juveniles, becoming much lower and less conspicuous in later growth stages; exterior ornamentation of more or less well-defined flat, concentric growth bands or ridges crossed by strongly developed broad, flattened costae on the anterior and posterior quarters of valves, occasionally with weaker radials located between stronger ones; the larger, wider radials (nearly plicae, involving the entire thickness of the valve) visible as weak corrugations along interior ventral margins, especially in juveniles; radial ornamentation lacking on mid-valve surfaces (except along ventral margins of mature individuals where it is weakly developed); costae equally strong on both ends, though covering slightly greater area on posterior surfaces; discontinuous microscopic striations radiating down the tops of larger costae in adults; hinge area, muscle scars, and pallial markings typical for the genus.

Holotype: ANSP 62892, Fig. 2b, c.

Paratypes: ANSP 62893, including broken valve shown in Fig. 2a.

Type locality: River bluff 0.3 km northwest of Smith Gut (a small, freshwater creek) and 3.4 km southeast of the center of the mouth of Beard Creek, north shore of Neuse River, southernmost Pamlico County, North Carolina (Fig. 1). This is the type section of the Smith Gut Member of the Flanner Beach Formation (Miller, this volume).

Stratigraphic horizon: Lowermost 0.5 m of bluff-face exposure, in bed of light olive-brown, shelly, muddy, fine to medium sand.

Discussion: Gouldia platycostata is distinguished from other western Atlantic-Caribbean species of *Gouldia* in having well-developed broad, flat, radial costae instead of the usual thin costae or reticulations seen in Late Cenozoic forms such as *G. cerina, G. burmudensis* (E.A. Smith, 1885), and *G. floridana* (Olsson and Harbison, 1953). This difference is so pronounced that a supraspecific category, to include only *G. platycostata,* seems justifiable. In terms of external morphology, *G. platycostata* is closest to the Indo-Pacific species described by E.A. Smith under the name *Circe amica* (1885, p. 145-146 and Plate II, Fig. 2-2e), which appears to be a *Gouldia* by virtue of lacking an escutcheon (see Cox *et al.*, 1969, p. N673). It is difficult to imagine how this species could be anything but a distant phylogenetic relative of *G. platycostata,* however, so I do not include the Indo-Pacific form in *Paragouldia.*

The new species is a rare component of the fossil association occurring in the Smith Gut Member. The sediments, fossils, and facies relationships suggest that this subunit of the Flanner Beach was deposited in a coastal bay setting, open to the Atlantic Ocean, during the early stages of coastal inundation at the beginning of an interglacial high-stand of sea level, approximately 200,000 years ago (Miller, this volume).

To my knowledge, *G. platycostata* has not been collected from other Pleistocene fossil deposits in the area, and apparently did not survive to the present. If this is the case, and if the species only lived during the time span when Smith Gut sediments were being deposited in eastern North Carolina, it is tempting to view this rare, isolated venerid as a failed evolutionary experiment–an "aborted species" in the terminology of Stanley (1979). In current macroevolutionary parlence aborted species are newly derived, descendant forms that do not survive the initial isolation and divergence from an ancestral population to establish a successful daughter species. Or, to use Stanley's aphorism, "many are called but few are chosen" (1979, p. 176). One of the possible explanations for the presence of rare fossils in collections of autochthonous faunal remains, in cases where stratigraphic occurrence is limited to a single level, is that these rarities are actually aborted species to be found nowhere else, no matter how much additional collecting be done. This specu-

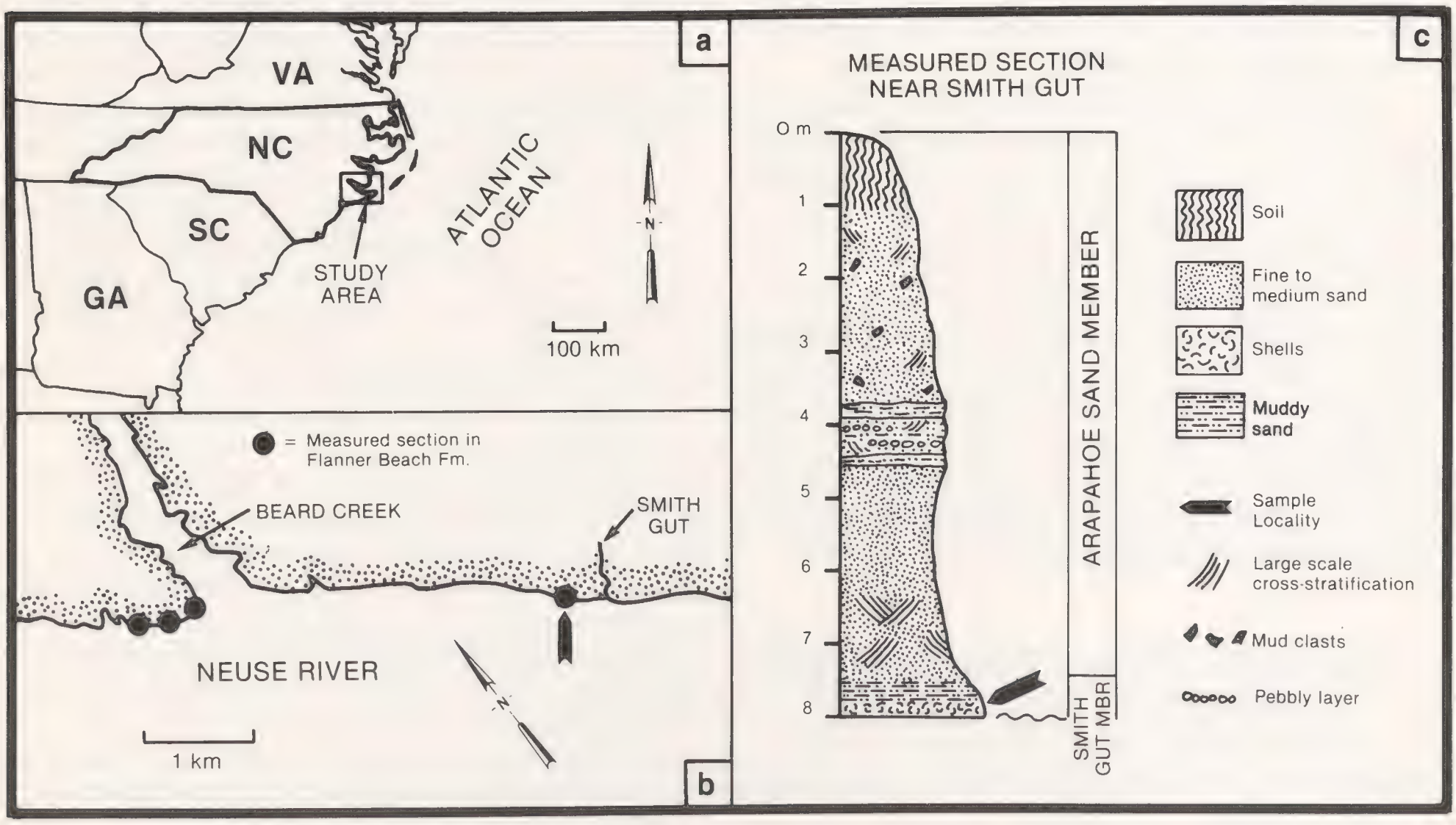

Figure 1. a, General location of collecting area; b, Detail of vicinity of type locality (indicated by arrow) on north shore of Neuse River; c, Measured section at the type locality.

lation about *G. platycostata* could be tested in part by searching for it in adjacent stratigraphic units (it does not occur elsewhere in the Flanner Beach). If found only in the coastwise temporal equivalents of the lower Flanner Beach Formation, *G. platycostata* will be proven a useful guide fossil, along with the very few other macrofossils so far recognized to have biostratigraphic potential in the Middle to Late Pleistocene of the Atlantic Coastal Plain (see Blackwelder, 1981).

The specific name is formed from the Greek term "platys," meaning broad and flat, and the Latin "costa," for rib.

I wish to thank Dr. Emily H. Vokes for her help with the literature and for carefully editing the manuscript, Mr. Henry C. Carter, IV, for the use of his motorboat and his field assistance during the trip to Smith Gut, and Ms. Sandi Potter for preparing the illustrations.

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December 5,1985

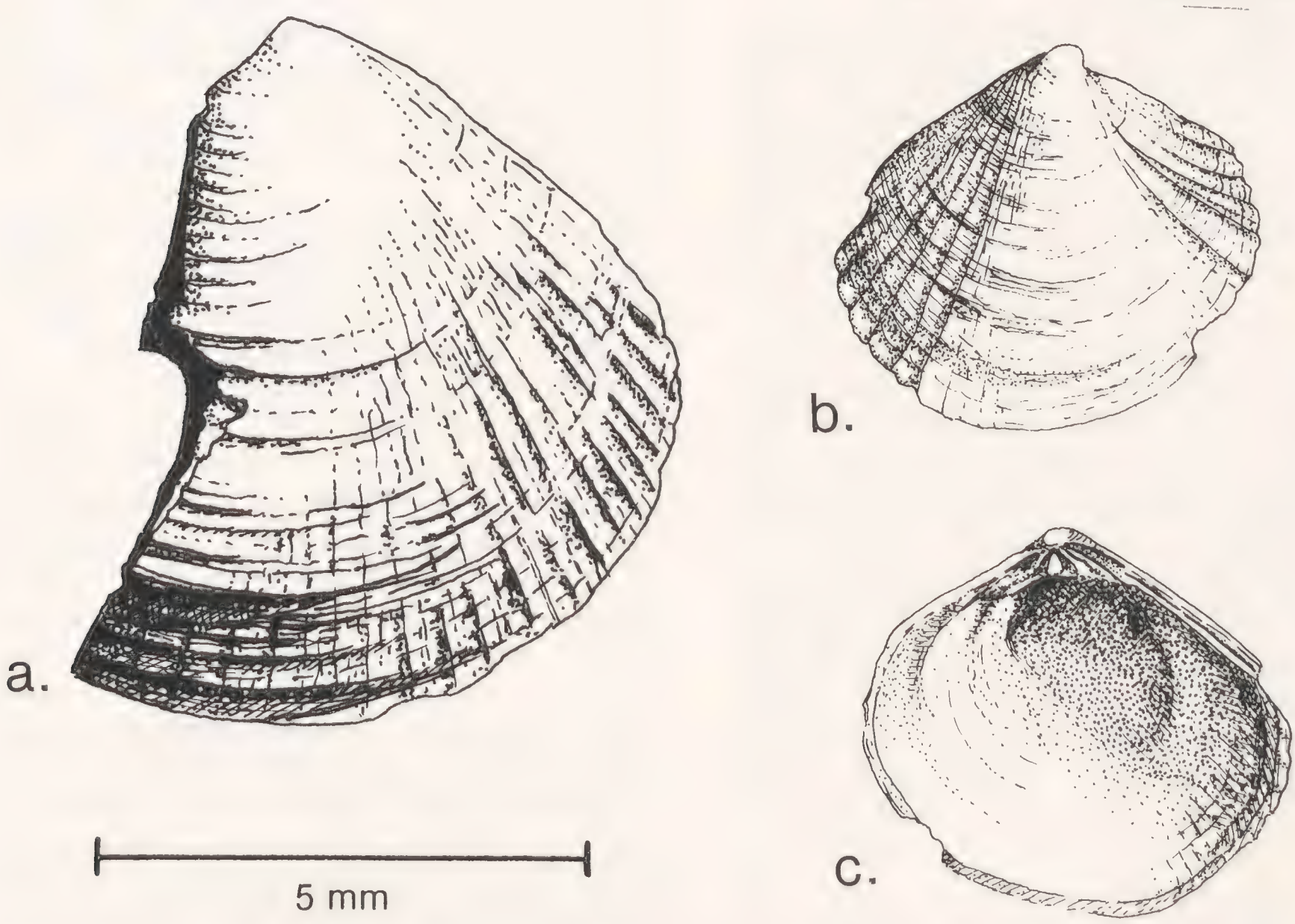

Figure 2. a, Exterior of adult valve of *Gouldia (Paragouldia) platycostata* n. sp. (ANSP 62893, a paratype); b, Exterior of the holotype of *G. (P.) platycostata* (ANSP 62892); c, Interior view of the holotype shown in b.

REVIEWS

AMERICAN GEOLOGICAL LITERATURE, 1669 to 1850, by Robert M. Hazen and Margaret Hindle Hazen. Published by Dowden, Hutchinson & Ross, Inc., Stroudsburg, Pennsylvania, 1980, xiii + 431 pp., index, casebound, $37.95

The literature of geology is enormous and appears in an extremely diverse variety of published forms including pamphlets, journal articles, notes, reviews, maps, broadsides, and other sources in addition to major books and geology-related whole titles. Research geologists and historians of geology are indebted to the Hazens for their thorough and scholarly approach to compiling this detailed bibliography of American geological literature.

This is the first attempt to produce a comprehensive compilation of all of the many minor and obscure sources as well as the primary source works in the literature of geology. The several previous bibliographies have been limited to listing only the major scientific works in American geology or to a single subject or facet of the voluminous literature.

The listings are limited to nonnewspaper sources published before 1851. All known published works from brief notes to articles to major whole titles are included from the early published description of an eruption of Mount Etna in 1669 to the end of 1850. Examination of the estimated two million pre-1851 newspaper issues was not feasible; thus, newspaper notes and articles are excluded. More than seven hundred early American journals were examined page by page for all earth science notes, reviews, and articles to supplement the listings compiled from eighty previous geology and general bibliographies, lists of the publications of individual geologists, various research library catalogs, and other published sources. The total of fifteen thousand references were consolidated into the 11,133 entries of this volume by combining multiple editions and the multiple publication of identical journal articles into single entries; in other cases very brief sequential notes on the same topic in certain journals are listed together in single entries.

This volume is a rich treasury of sources for the historian and the research geologist. The task of background research will be greatly facilitated for all students of American geology through this carefully compiled bibliography. It seems regrettable that it stops at mid-century, but the authors reveal than an extension to 1860 would double the number of entries. Thus, their decision to end the work with 1850 is readily accepted.

ATLAS OF DINOFLAGELLATES: A Scanning Electron Microscope Survey, by John D. Dodge. Published by Farrand Press, London, 1985, vii + 119 pp., 150 SEM illustrations, cloth, $25.00 (distributed by Blackwell Scientific Publications)

The world of dinoflagellates, the "red-tide" organisms, was poorly known until recent years when the scientific breakthrough demonstrating the relationship of fossil hystricospheres to living dinoflagellates occurred and a renewed and definitive study of these delicate and complicated forms was made possible by the development of the scanning electron microscope. In this atlas, the stunning beauty of these delicate forms and their complicated tabulation patterns are magnificently illustrated.

A brief introduction to the dinoflagellates, their definition, physiology, habitats, and descriptive morphology is included at the beginning of the book followed by an outline classification and the atlas of 150 selected SEM photomicrographs illustrating as many genera and species of dinoflagellates as possible. In the preface, the author discusses the economic importance of the dinoflagellates as a major link in aquatic food chains and as a major component in the phytoplankton, their ability to produce toxicity in mollusks,which can be fatal to man, and their usefulness in dating stratigraphic sequences from fossil floras.

This volume will serve the serious student as a most useful handbook illustrating the variety, the morphology, and the biological significance of this important group of organisms. It is a pleasure to view and use and is highly recommended.

—H.C.S.

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

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ECOLOGY AND STRATIGRAPHY OF THE ECHINOIDS OF THE OCALA LIMESTONE (LATE EOCENE)

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I. ABSTRACT

The Ocala Limestone (Late Eocene) of Florida may be zoned using echinoids. In addition to biostratigraphic zonation, three separate echinoid communities may be recognized utilizing species differing in specimen size and substrate affinity. The communities present are: 1) a community of large echinoids, which are sand-dwellers; 2) a community characterized by mud-dwelling echinoids, as well as a few small species with affinities for a sandy substrate; and 3) a community of sand-dwelling echinoids of large size, the composition of which is different from that of community 1. The stratigraphic distribution of these three communities reflect physical changes in the environment of deposition, which may be explained by several hypotheses, but probably reflect a transgressive-regressive sequence.

II. INTRODUCTION

The echinoid fauna of the Ocala Limestone in northwestern peninsular Florida (Text-fig. 1) is abundant and diverse, yet few studies have dealt with this fauna. The majority of previous works have been taxonomic, and none has concentrated exclusively on the ecology of the echinoid fauna. The purpose of this study is to explain the temporal distribution of echinoids within the Ocala Limestone.

The Ocala Limestone has been stratigraphically zoned in a variety of ways (Vernon, 1951; Puri, 1957; Cheetham, 1963; McCullough, 1969; Hoganson, 1972; Hunter, 1976; and Zachos and Shaak, 1978). The zonation proposed by Zachos and Shaak (1978), based on echinoids, is used in this study (Text-fig. 2).

The flat-lying Ocala Limestone crops out in two areas in Florida: northwestern peninsular Florida and the northern central panhandle. This study is limited to outcrops of peninsular Florida, which occur around the Ocala High. The outcrop pattern of the Ocala Limestone in this area exhibits an elongated northwest-southeast trending pattern, approximately 200 km long and 80 km wide. A structural high, flanked by younger deposits, is situated in the center of the Ocala outcrop pattern (Text-fig. 1).

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Rock types of the Ocala Limestone include grainstones, packstones, and wackestones. These massive limestones are pure, cream to white, varying from soft, chalky, and friable, to hard and crystalline. Bedding in the Ocala is seldom apparent and portions are dolomitized. The Ocala is approximately 120 meters thick in northwestern peninsular Florida.

The Ocala Limestone is included in the Jackson Stage (Late Eocene) and Croft (1980) has correlated the formation, based on echinoids, with the P16 Foraminiferal Zone of Blow (1969). In northwestern peninsular Florida the Ocala Limestone lies unconformably above the Avon Park Limestone (Middle Eocene) and is overlain unconformably by the Suwannee Limestone (Oligocene).

The Ocala Limestone in northwestern peninsular Florida contains a diverse and abundant fauna. Irregular echinoids, gastropods, pelecypods, bryozoans, starfish (ossicles), ostracods, and foraminifera are common. Cheetham (1963) described 36 species of cheilostome bryozoa from the Ocala Limestone. Meeder (1976) reported 77 molluscan species from the Inglis Formation (Late Eocene). Puri (1957) reported a total of 142 foraminiferal species and 40 ostracod species from the Ocala. The most comprehensive summaries on the Ocala echinoids can be found in Cooke (1959), Fischer (1951), and Croft (1980). Thirty-two irregular echinoid species representing 16 genera are present in the Ocala Limestone. Four of these species were reported as new by Croft (1980).

Most modern irregular echinoids are extremely sensitive to the type of substrate in which they burrow and comparison of the functional morphology of fossil and modern echinoids can link each echinoid species to the type of substrate in which it most likely lived. Each of the 32 irregular echinoid species (Text-fig. 3) found in the Ocala Limestone are determined to have been sand-dwellers or mud-dwellers. The sand-dwelling echinoids are primarily restricted to the lower and upper Ocala, whereas the middle Ocala is characterized by a higher percentage of mud-dwelling echinoids and, more importantly, by lack of the large sand-dwelling echinoids. This observation indicates that substrate composition changed during deposition of the Ocala from sandy to muddy, then back to sandy substrate. Such a change in bottom conditions is probably the result of varying water depths, indicative of a transgressive-regressive sequence.

III. BIOSTRATIGRAPHY

Ideally, planktonic organisms should be used to establish biostratigraphic zones in sedimentary beds. However, there are few planktonic organisms preserved in the Ocala Limestone; consequently, biostratigraphic zonation must be based on benthic organisms. Irregular echinoids may be used to zone the Ocala easily due to: 1) the relative abundance of irregular echinoids; 2) distinct breaks in the echinoid stratigraphic distribution; and 3) the ease of echinoid identification in the field.

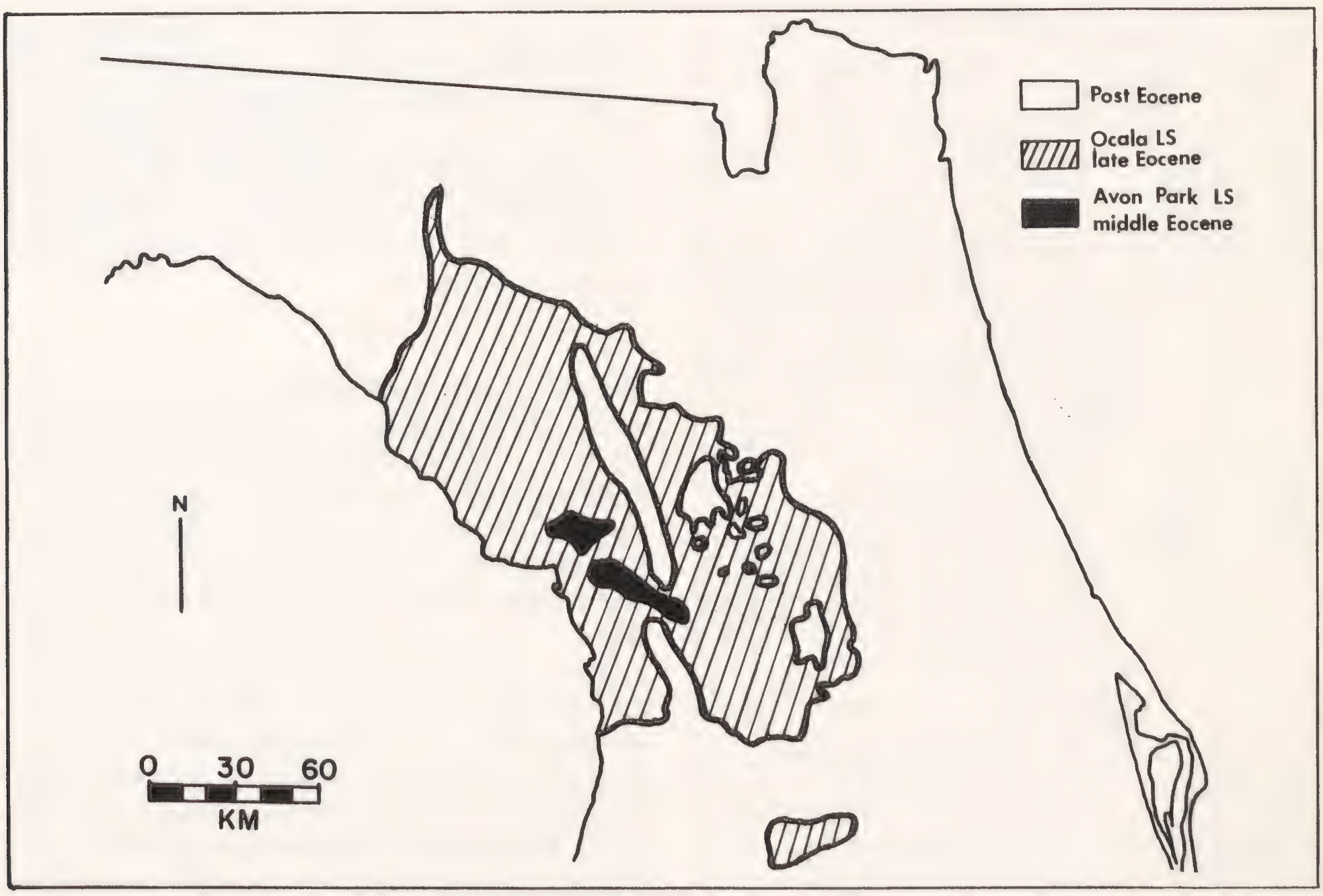
Most echinoids species are adapted for specific substrate conditions, and consequently their stratigraphic distribution is strongly controlled by the lithofacies. The stratigraphic distribution of most echinoid species in the Ocala is a function of the substrate composition, and reflects an ecological zonation rather than a true time-evolutionary zonation. But there are exceptions. Zachos and Shaak (1978) proposed a zonation of the Ocala Limestone based on three species of *Oligopygus* (Echinoidea): *O phelani* Kier, *O. haldemani* (Conrad) and *O. wetherbyi* de Loriol (Text-fig. 2). The stratigraphic distribution of these species of *Oligopygus* seems to be controlled little, if any, by the changing substrate types inferred for the Ocala during deposition; consequently, they probably represent a time evolutionary sequence (see Paleoecology section).

Due to the obvious ecologic control over most echinoid species of the Ocala Limestone, it is surprising that these three species seem to have been relatively unaffected by ecologic changes. However, changes in relative abundance suggest that the number of individuals (of *Oligopygus*) may have been affected by changing substrate conditions. Specimens of *O. phelani*, the first member of this lineage, are not abundant, perhaps because the species had not yet established itself in the community. A subsequent increase in specimens at the first occurrence of *O. haldemani* indicates the genus had begun to establish it-

self. *Oligopygus* reaches its lowest abundance in the middle Ocala, but increases again in the upper Ocala. This suggests that the muddy substrate conditions present at the time of deposition of the middle Ocala may have affected the ability of *O. haldemani* to compete, but obviously not to the same degree as most other echinoids found in the Ocala. The apparent ability of *Oligopygus* to withstand more hostile ecological conditions than other echinoids at that time make it an excellent zonal marker.

The three *Oligopygus* species divide the Ocala into three interval and two concurrent range zones (Text-fig. 2). There is little overlap in the ranges of these three species. The interval of rock containing both *O. phelani* and *O. haldemani* is generally only about one meter thick or less. The thickness of the interval of rock containing both *O. haldemani* and *O. wetherbyi* is uncertain, but is certainly no more than one or two meters. The intervals of rock containing the concurrent range zones are rarely seen in outcrop, and for practical purposes only three interval range zones are used in this study: the *O. phelani*, *O. haldemani*; and *O. wetherbyi* biozones.

These three species of *Oligopygus* in the Ocala Limestone exhibit an evolutionary trend that can be traced easily. There are three morphological features that change with time; the shape of the peristomial depression, the position of the periproct, and test size; the latter increasing through time (see Table 1). *Oligopygus phelani*, found in the lower third of the Ocala, has a small, circular peristomial depression and the periproct is inframarginal (Text-fig. 4 A). *Oligopygus haldemani* found in the middle third of the Ocala, exhibits a transverse peristomial depression and the periproct is inframarginal (Text-fig. 4 B). *Oligopygus wetherbyi* from the upper third of the Ocala has a transverse peristomial depression as in *O. haldemani*, but the periproct is located about one half the distance to the peristome (Text-fig. 4 C).



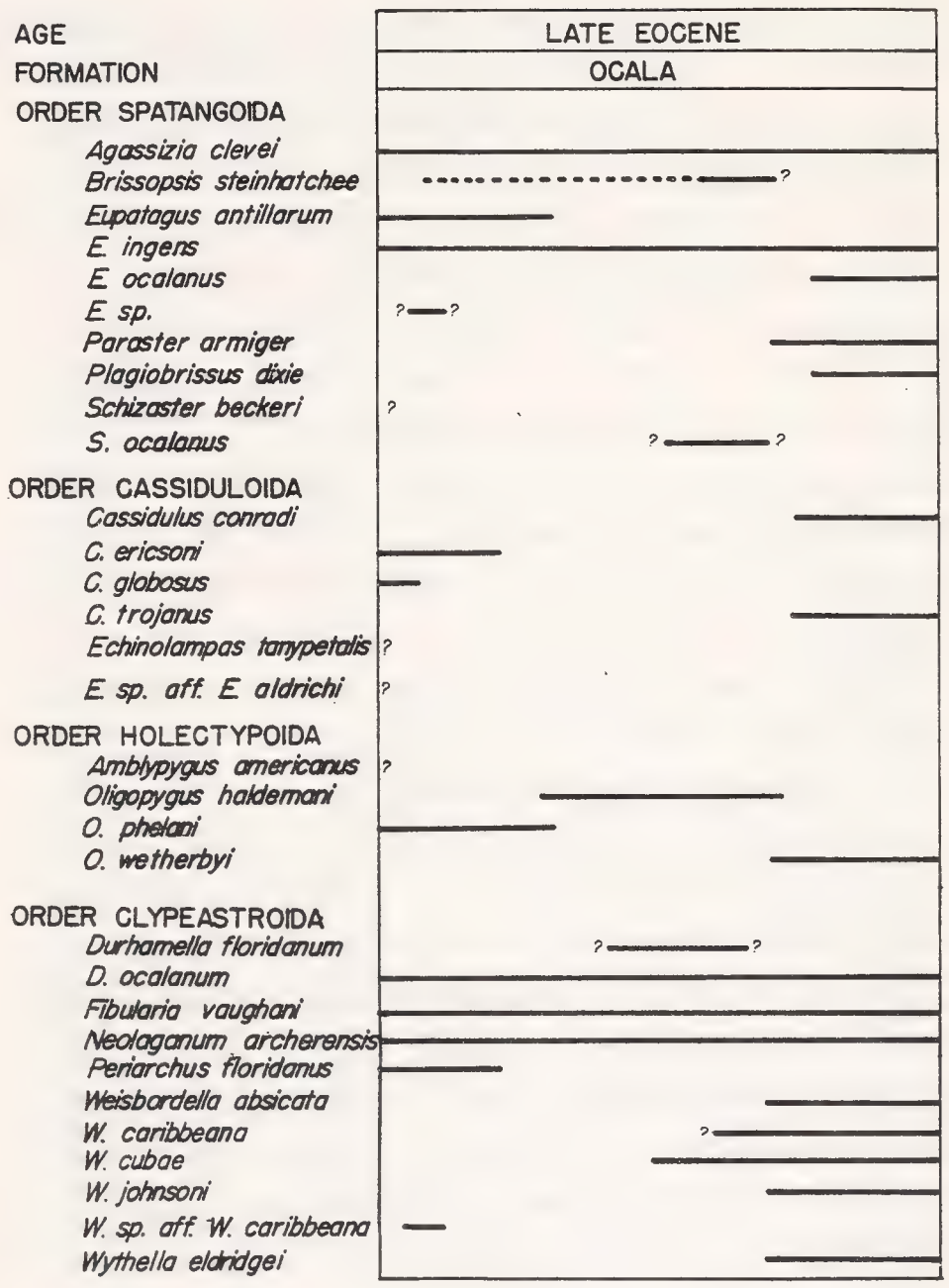
Text figure 1. Surface exposures of the Ocala Limestone in northwestern peninsular Florida (after Puri and Vernon, 1964).

IV. PALEOECOLOGY

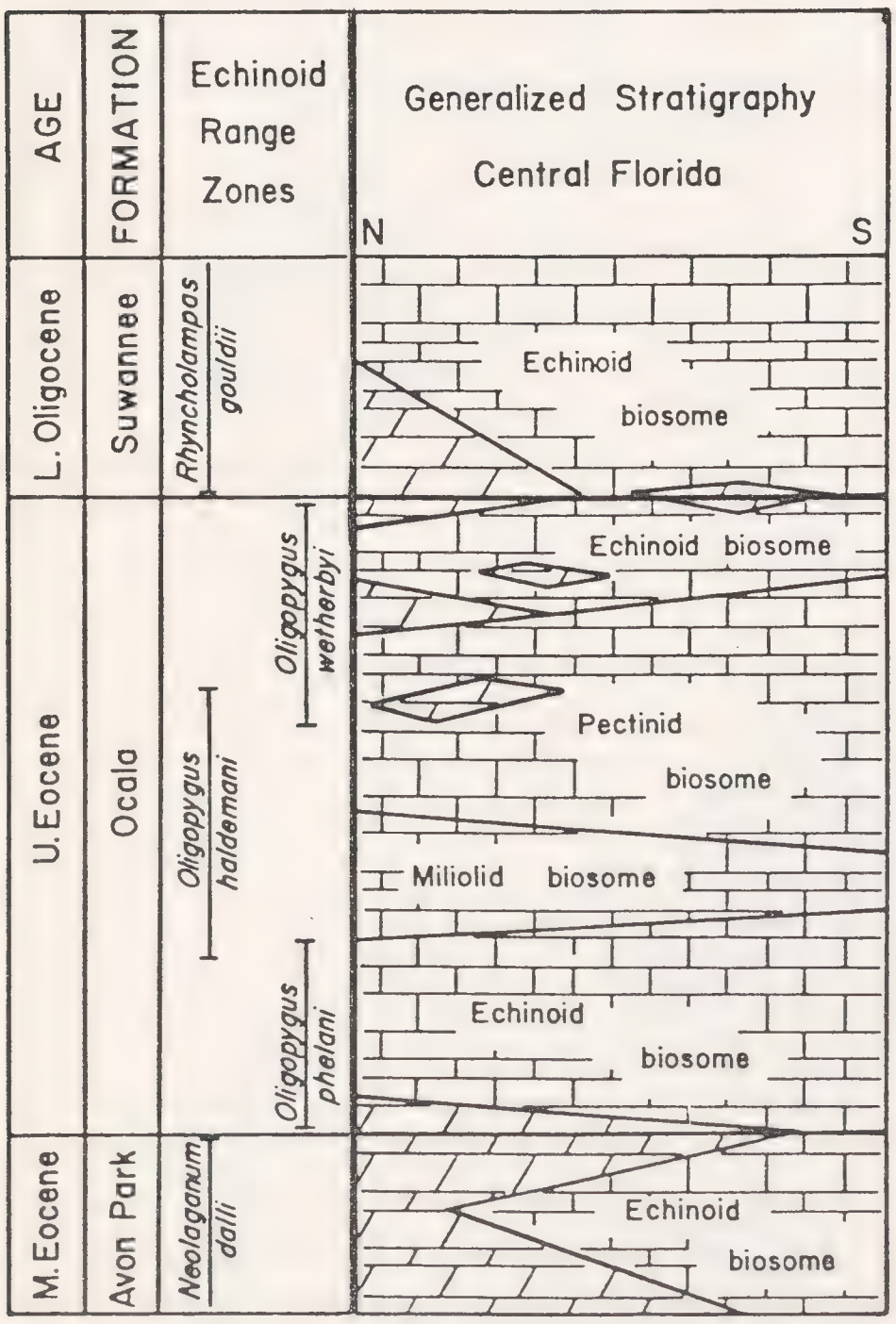
Paleoecological interpretations are based on fossil assemblages in the study strata. Biostratinomic and taphonomic alteration of fossil assemblages must be recognized and interpreted before sound interpretations of the depositional environment can be determined (Fagerstrom, 1964). Biostratinomic alteration is that resulting from predators, scavengers, and bottom currents. Taphonomic alteration includes replacement, leaching, and crushing of tests.

Factors that were evaluated to determine the amount, if any, of biostratinomic alteration of the Ocala Limestone echinoid fauna are (1) size-frequency distributions, (2) ratio of whole to fragmental tests, (3) orientation of fossils, and (4) preservation of fossils.

Size-frequency distributions for echinoid populations of the Ocala are difficult to



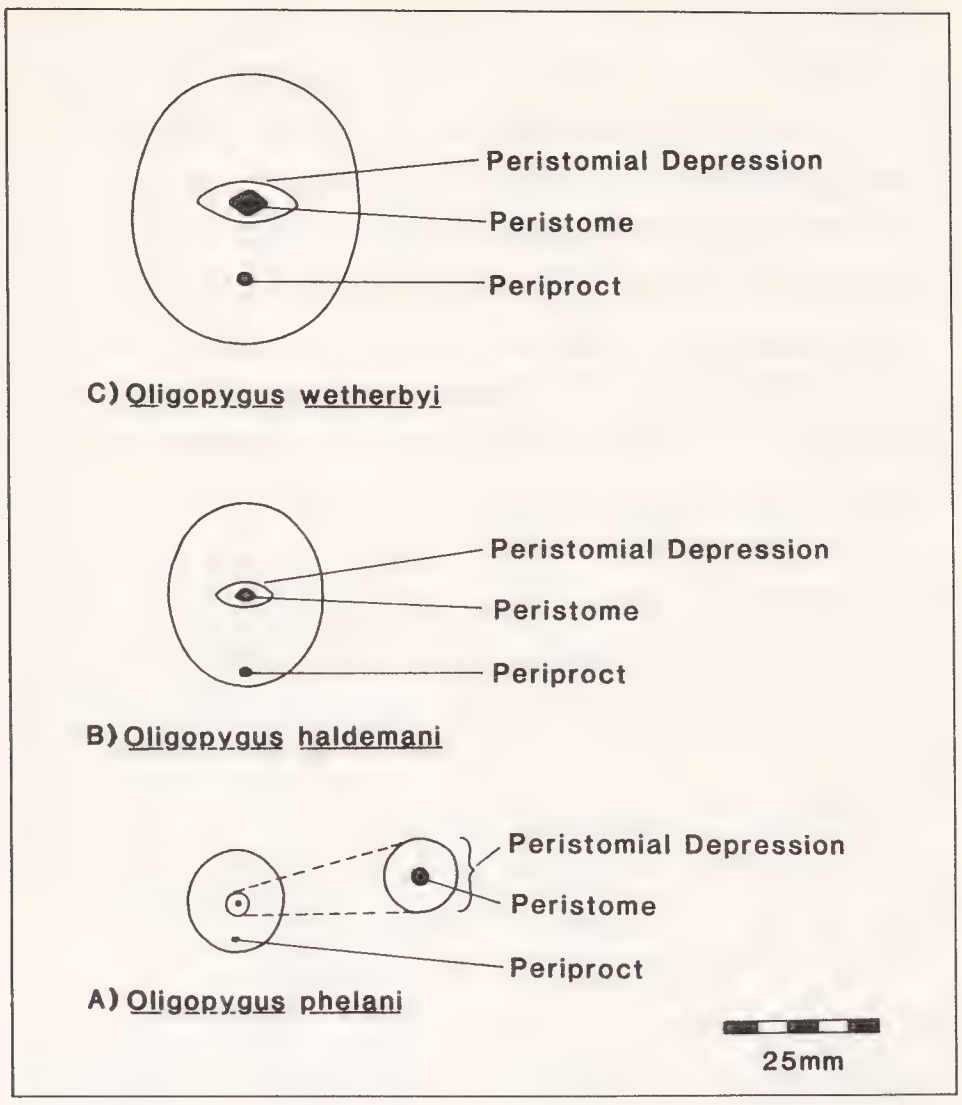
Text figure 3. Stratigraphic range chart for the irregular echinoids of the Ocala Limestone. A question mark beside the species name indicates that the stratigraphic range of that species is uncertain. A question mark beside the range line of a species indicates that portion of the stratigraphic range is uncertain.



Text figure 2. Echinoid bistratigraphic zonation of the Ocala Limestone (Zachos and Shaak, 1978).

quantify, as much collecting has to be done from spoil piles and float material; however, a typical echinoid assemblage includes specimens ranging from several mm to 100 mm in diameter. This observation suggests that few, if any, specimens were selectively removed by bottom currents.

The ratio of whole to fragmented tests is qualitatively estimated to be approximately 5:1, but this ratio varies between species, and is partially a function of test fragility of each species, as some species *(e.g., Oligopygus wetherbyi)* have much thicker tests than others *(e.g., Paraster armiger)*. The tests of most echinoid species are seldom crushed, but the tests of *Periarchus floridanus* (Fischer) are nearly always broken, probably due to their large,



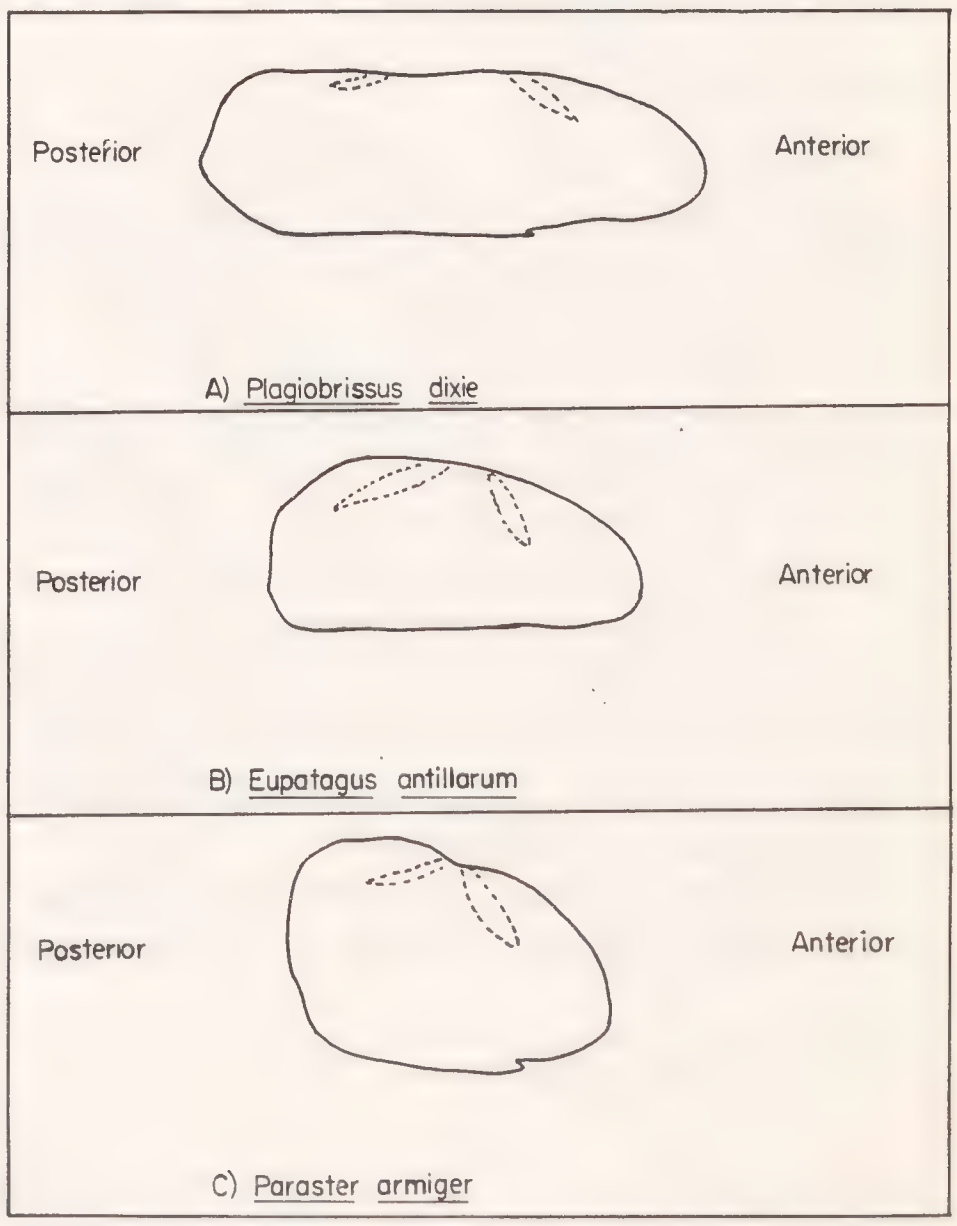
Text figure 4. Morphological variations in *Oligopygus* from the Ocala Limestone.
a) *O. phelani* – small test size, circular peristomial depression, and inframarginal periproct.
b) *O. haldemani* – medium test size, transverse peristomial depression, and inframarginal periproct.
c) *O. wetherbyi* – large test size, transverse peristomial depression, and periproct located halfway between the peristome and test margin.

thin, flat construction. Tests of sand-dwelling echinoids of small size are often broken, a result of their fragile tests.

The effect of predation and scavenging on the whole to fragmented test ratio is not entirely known. Many different organisms, such as starfish, crabs, large fish, mammals, and gastropods prey upon echinoids and the remains of starfish (ossicles), crabs, and gastropods are common in the Ocala Limestone. Moore (1956) reported that three species of *Cassis,* a helmet conch, feed upon modern spatangoids. The gastropods bore through the echinoid test, producing a conspicuous round hole. Many Ocala Limestone echinoids display borings typical of preying gastropods.

The effect upon echinoids by preying starfish, crabs, fish, and mammals is uncertain, but the predator probably crushes the echinoid test to feed upon it. Predation by gastropods would have little effect on the whole to fragmented test ratio, but predation by starfish, crabs, fish, and mammals would certainly decrease the ratio. The relatively high, whole to fragmented test ratio indicates minimal biostratinomic alteration.

Generally, there is no preferred orientation of echinoid tests in the Ocala Limestone, indicating no selective deposition. Few echinoids are in life position. This observation indicates the presence of bottom currents strong enough to transport echinoid tests, but only for short distances. The test surfaces of most Ocala echinoids show little evidence of significant preburial transportation. Echinoid tests are generally fragile, and any significant preburial transportation would certainly destroy them. However, slightly crushed tests or pits and scratches on the outer surface in-



Text figure 5. Lateral views of a) *Plagiobrissus dixie,* b) *Eupatagus antillarum*, and c) *Paraster armiger*. The higher the posterior end of the test with respect to the anterior end, the deeper the echinoid burrows into the substrate (Nichols, 1959).

dicate that many of the echinoids have undergone minor preburial transportation. Specimens from the middle Ocala are less commonly broken than those found in the lower and upper Ocala.

With few exceptions, taphonomic alteration of the Ocala echinoid fauna is minimal. Most of the echinoids have been permineralized by calcite, and it is doubtful that any single population was selectively replaced. Areas of intense solution and dolomitization (diagenesis) reflect taphonomic alteration. In such areas, leaching and recrystallization, respectively, have obliterated most fossils. Most of the fossils found in the dolomitized rocks are preserved as molds.

The preceeding qualitative evaluation indicates that the Ocala Limestone echinoid fauna lived, died, and was preserved at or near the site of deposition. Many specimens were probably moved short distances within the area of deposition, as indicated by abraded and broken tests, especially those of the large sand-dweller, *Periarchus floridanus*.

General Statement

Echinoids are stenotypic, vagrant, benthic organisms. Salinity, temperature, substrate type, and water depth are the major factors controlling their spatial distribution. They are dependent upon a constant, normal marine salinity (Boolootian, 1966; Ernst and Seibertz, 1977). Although echinoids can be used to make generalized water temperature interpretations, the extant genera found in the Ocala Limestone presently inhabit water ranging from tropical to temperate and yield little information on specific water temperatures at the time of deposition of the Ocala.

The wide depth range of extant genera in the Ocala Limestone (Beu, Hendersen, and Nelson, 1972) gives no clues as to the precise water depth at the time of deposition. The distribution of echinoids is more dependent on substrate conditions than water depth. In part, this is due to their intimate relationship with the bottom for nutrient supply, waste disposal, and protection. The type of substrate suitable to any species is reflected in the test morphology (Nichols, 1959). Most modern echinoid species can live in a wide range of water depths, but most are restricted to a particular type of substrate. Fossil echinoids serve as excellent tools for determining the grain-size of the substrate on or in which they live. Irregular echinoids are predominantly infaunal organisms, although epifaunal forms are not uncommon.

The distribution of echinoids in the Ocala Limestone is not only useful for biostratigraphic zonation (Text-figs. 2 and 3), but also reflects changes in the environment of deposition of the Ocala Limestone. When one ties the sediment preferences of the echinoids to their stratigraphic distribution, the presence of three distinct communities can be recognized. These are here referred to as Community I (*Periarchus floridanus – Eupatagus antillarum* Community), Community II (*Agassizia clevei* Community), and Community III (*Wythella eldridgei – Paraster armiger* Community). These three communities will be defined later, but basically the species comprising these three communities differ in substrate affinity, specimen size, and abundance.

The inferred substrate type for the Ocala Limestone varies from clay- to sand-sized particles of carbonate composition. Sand-dwelling species are described as small or large (this report only), depending upon the most common test size. Those spatangoid and clypeasteroid species commonly

Table 1

Range in specimen size of *Oligopygus phelani*, *O. haldemani*, and *O. wetherbyi*

	Test length (mm)	*Test width (mm)*	*Test height (mm)*
Oligopygus phelani	6-17	4-15	3-7
Oligopygus haldemani	9-35	7-30	4-15
Oligopygus wetherbyi	25-55	20-55	10-25

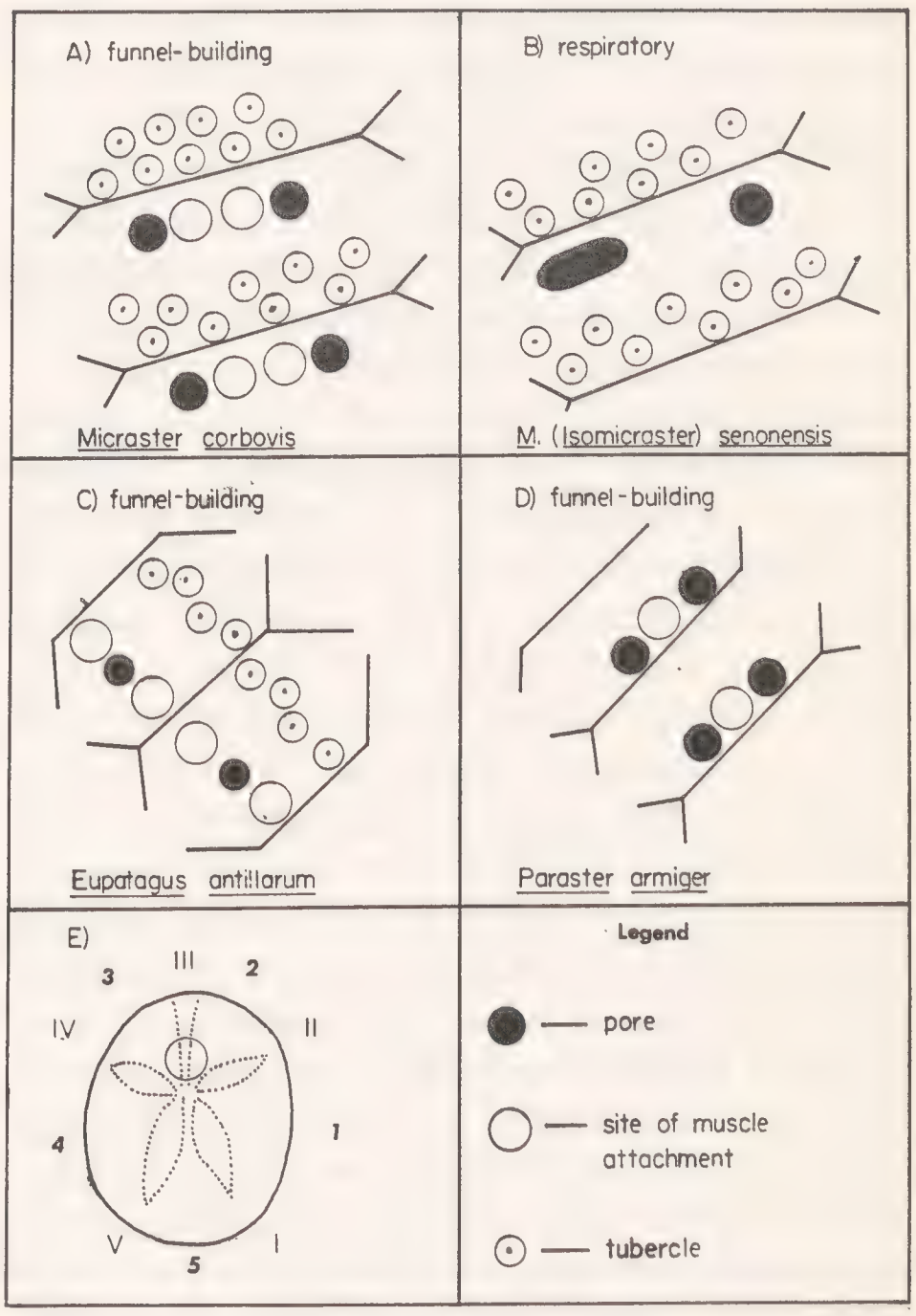
having a test length less than approximately 40 mm are considered small. Those commonly having a test length greater than approximately 60 mm are considered large. The cassiduloids, represented in the Ocala almost entirely by *Cassidulus*, are all sand-dwellers, and regardless of test size are restricted to Communities I and III. Communities I and III, as will be shown later, are composed almost totally of sand-dwelling echinoids. However, in order to follow the general size scheme of large and small echinoid species, an arbitrary value of 35 mm length has been selected to divide the cassiduloids into small and large species. Individual specimen size may vary beyond these arbitrary limits.

Echinoid test morphology normally reflects the type of substrate preferred by the organism and many of the Ocala echinoids exhibit morphological features indicating the original texture of the sediments. The most useful morphological features among the spatangoids are fascioles, ornamentation and pore size of the dorsal ambulacrum (III in Lovens system of numbering the ambulacral and interambulacral plates), and test shape. Comparisons with modern forms are also helpful. Estimates of the grain size of the substrate inhabited by the clypeasteroid species are based on functional morphology and analogues with modern forms. Determination of the type of substrate inhabited by the cassiduloids is based on comparison with moden forms.

Functional Morphology

The general test shape of *Eupatagus antillarum* is similar to that of many modern burrowing echinoids. The test is realtively high at the posterior end and low at the anterior end (Text-fig. 5B). Nichols (1959) interpreted the relatively higher posterior end as a trend towards deeper burrowing. Nichols also pointed out that many modern burrowing spatangoids, depending upon sediment grain-size, must maintain an open funnel to the sediment surface in order to obtain a supply of fresh oxygenated water to pass over the petaloid region, the location of the respiratory tube feet. The funnel is built and maintained by larger, specially adapted tube feet located in ambulacrum III (Text-fig. 6). Ridges or bumps located around the pore for each of these tube feet mark the site of muscle attachments used in the operation of these larger tube feet (Text-fig. 6A). The smaller tube feet used for respiration have no need for the ridges or bumps flanking the pores from which they protrude (Text-fig. 6B).

Fossil echinoids that, when alive, built a funnel to the sediment surface can be recognized by the presence of such ridges or bumps in ambulacrum III. However, Smith (1980) reports that funnel-building tube feet are not necessarily muscular, and do not always have associated ridges or bumps. *Eupatagus antillarum* has such ridges in ambulacrum III (Text-fig. 6C) and, presumably, had a series of large tube feet, used to build and maintain the respiratory funnel.



Text figure 6. a-d) Morphology of ambulacrm III with respect to burrowing affinity (a and b from Nichols, 1959). e) Location of ambulacral plates in a-d, and Lovens system of numbering the ambulacral and interambulacral plates. I-V: ambulacras plates; I-5: interambulacral plates.

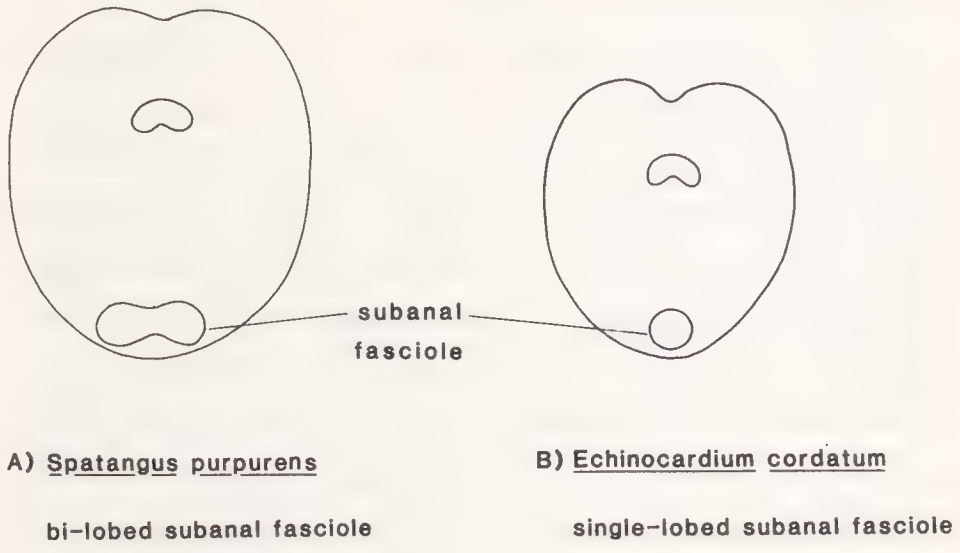
The fasciole is a narrow band of small densely ciliated spines; these cilia beating to create currents that augment normal body ciliatory currents used for respiration, nutrient gathering, and waste disposal. There are six basic types of fascioles – anal, subanal, internal, marginal, lateral, and peripetalous. Each fasciole, or combination of fascioles, reflects various modes of burrowing. *Eupatagus antillarum* has a lateral and subanal fasciole. The lateral fasciole would have aided normal body ciliation in drawing water down through the funnel over the petaloid ambulacra, indicating a burrowing habitat.

Eupatagus antillarum has a series of large tubercles on its aboral surface. By analogy with modern echinoids (Nichols, 1959) these spines maintained contact with the sediment surface during initial stages of burrowing, when a funnel would be most difficult to maintain, and may remain in contact with the sediment surface during burrowing. Echinoids that build a funnel to the sediment surface live in either a sandy or muddy substrate, not a shelly gravel (Nichols, 1959). The large interstices in a shelly gravel negate the need for a respiratory funnel, as water can easily be drawn through them.

In addition to a lateral fasciole *E. antillarum* has a single-lobed subanal fasciole. This indicates that *E. antillarum* was a sand-dweller, not a mud or shelly gravel-dweller. The subanal fasciole is used to build a small tunnel to the rear of the test for sanitary waste disposal. The size and shape of the tunnel is a function of the cohesiveness of the substrate. For stability, the tunnel is lined with mucus, secreted by the echinoid. A tunnel built in mud or shelly gravel requires less mucus per unit area to maintain than one in sand, due to the physical interlocking of large particles in the shelly gravel and flocculation in the mud (Nichols, 1959). Consequently, echinoids living in a shelly gravel or mud build and maintain two sanitary tunnels and exhibit a bi-lobed subanal fasciole (Text-fig. 7). Echinoids living in sand require more mucus per unit area to line the tunnel than in mud or shelly gravel; they build and maintain only one sanitary tube and exhibit a single-lobed subanal fasciole (Text-fig. 7B).

The test shape, the ornamentation of ambulacrum III, and the nature of the fascioles together indicate that *E. antillarum* burrowed into a sandy substrate. The relationship of the posterior and anterior test height is an indication of burrowing depth. The higher the posterior end with respect to the anterior end, the deeper the echinoid burrows. *Paraster floridiensis* Kier and Grant, morphologically similar to *P. armiger*, burrows to a depth of approximately 25 cm (Chesher, 1966). *Plagiobrissus grandis* (Gmelin), morphologically similar to *P. dixie* (Cooke) (Text-fig. 5A), burrows to a depth of only several cm (Kier and Grant, 1965). *E. antillarum* is morphologically intermediate between *P. armiger* and *P. dixie* (Text-fig. 5B), it is estimated to have burrowed to a depth of approximately 5-10 cm.

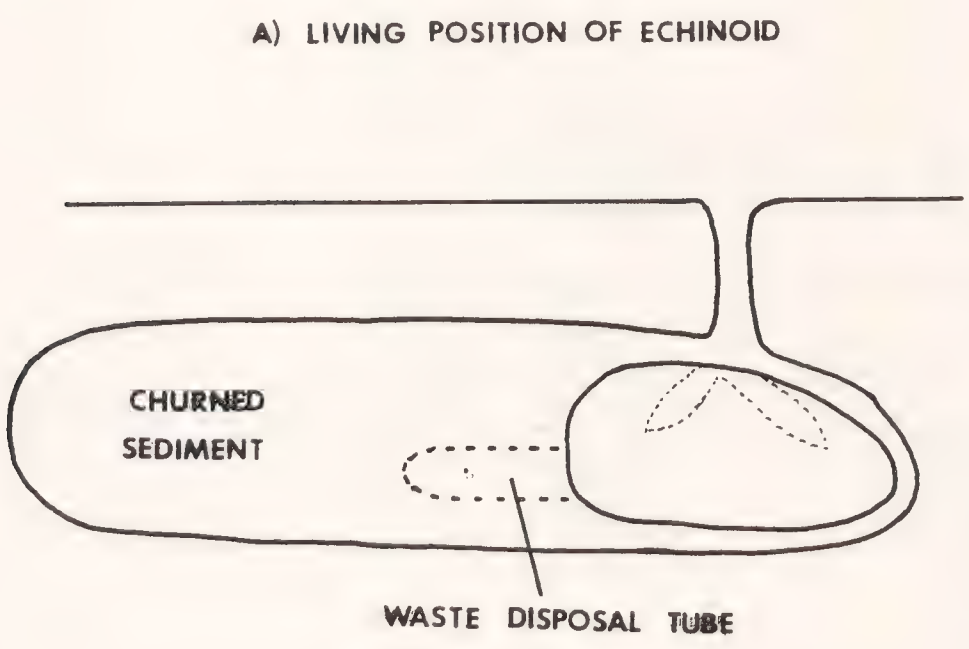
Similar arguments can be made for *Paraster armiger* and *P. dixie* to show that they were sand-dwellers. *Paraster armiger* has a peripetalous, a lateral, and an anal fasciole. The presence of lateral and peripetalous fascioles, as well as a markedly higher posterior end than occurs in *E. antillarum* (Text-fig. 5C), indicates that *Paraster armiger* burrowed deeper than *E. antillarum*. Peripetalous and lateral fascioles together would produce stronger currents than a lateral fasciole alone. Consequently, water could be drawn down a longer funnel, allowing *Paraster armiger* to burrow deeper. The anal fasciole of *P. armiger* was used to build a single waste dis-



Text figure 7. Sketches of a) *Echinocardium cordatum* showing bi-lobed subanal fasciole, and b) *Spatangus purpurens* single-lobed subanal fasciole. (Taken from Nichols, 1959, Fig. 1.)

posal tunnel, much like the one built by *E. antillarum*. *Paraster floridiensis*, a modern species living in the Bahamas and Florida Keys, burrows in calcareous sand to depths of approximately 25 cm (Chesher, 1966). *Paraster armiger* probably burrowed to an equivalent depth. However, Kier (1975) reports *P. floridiensis* and *P. doederleini* living in mud, offshore Carrie Bow Cay, Belize.

Plagiobrissus dixie has a peripetalous and a single-lobed subanal fasciole. It differs from *Paraster armiger* and *E. antillarum* in that the anterior and posterior test ends are approximately equal in height (Text-fig. 5C). This morphology indicates that *Plagiobrissus dixie* was a shallow sand-burrower. *Plagiobrissus dixie* has a series of large tubercles located on its aboral surface similar to those found on the aboral surface of *E. antillarum*, suggesting a tuft of large spines used during initial stages of burrowing. However, these spines may have been for defense. The poor state of preservation of most specimens prohibits any conclusions based on analysis of ambulacrum III. Kier (1965) found *Plagiobrissus grandis*, larger but morphologically similar to *P. dixie*, burrowing in shallow, relatively grassless sand. Functional morphology and the modern analogue indicate that *P. dixie* was a shallow burrower (several cm) in a sandy substrate.



Text figure 8. Relationship between an echinoid burrow (a) and the tubes found in the Ocala Limestone interpreted as preserved echinoid burrows (b).

Agassizia has a small, high globular test. Living species of *Agassizia* have been observed burrowing in mud (Clark, 1910) and sand (Mortensen, 1951). Substrate affinity and burrowing habitat are generally related to test morphology on a generic level; hence, most species of a particular genus have similar substrate and burrowing preferences. *Agassizia clevei* Cotteau was probably capable of burrowing into a sandy or muddy substrate. The mechanics governing the functional morphology is uncertain, but the affinity of *Agassizia* for both sandy and muddy substrates is possibly a function of its small test size. *Schizaster ocalanus* Cooke has a small, high, globular test similar to *Agassizia clevei;* therefore, it seems reasonable that *S. ocalanus* was also capable of burrowing into sandy or muddy substrates.

Brissopsis steinhatchee Cooke has a bilobed subanal fasciole and a peripetalous fasciole, indicating that it burrowed into a muddy substrate. *Brissopsis luzonica* (Gray) (Mortensen, 1951), *B. elongata* Mortensen (Kier, 1975), and *B. lyrifera* (Forbes) (Mortensen, 1977) are reported burrowing into muddy sediments.

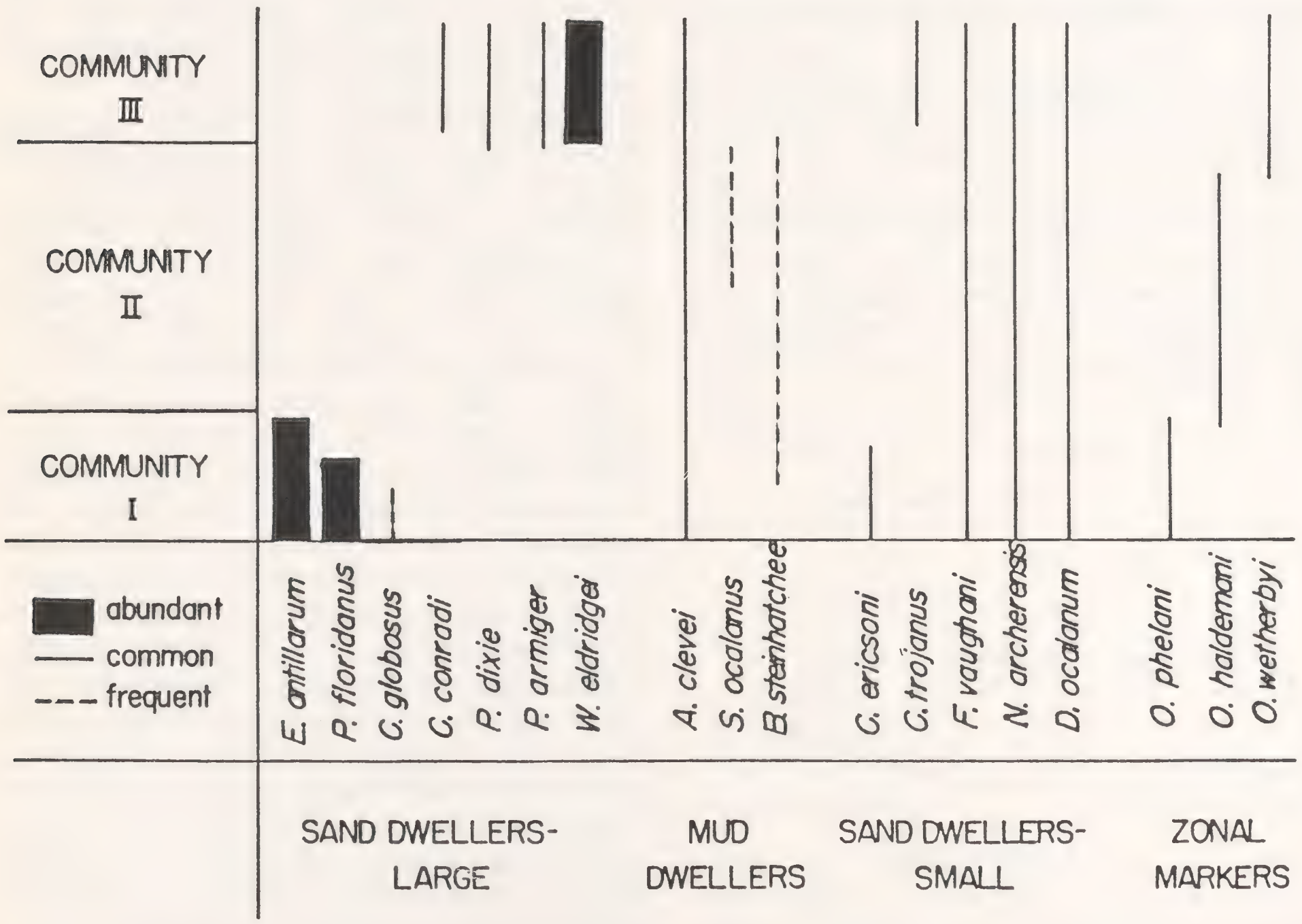
If, in fact, the heart urchins (spatangoids) of the Ocala Limestone were burrowers, then it would seem logical to find preserved echinoid burrows. There are many organisms that burrow into the substrate in nearshore marine environments, and it is often quite difficult, if not impossible, to assign a fossil burrow to a specific organism. Vernon (1951) reported the occurrence of elongated tubular structures in the Ocala Limestone. These structures have been described as sponges, holothurians, concretions, and burrows. The tubes range in size from approximately 30 mm long and 10 mm in diameter to over 230 mm in length and 100 mm in diameter. Almost every tube has a small, elongated, circular, distal depression about 10-30 mm deep, which lies parallel to the long axis of the tube. The diameter of this depression

is typically one-half that of the tube diameter. These tubes may be preserved spatangoid burrows. The small depression in the end might be the remnants of the waste disposal tube (Text-fig. 8). The tubes are similar in appearance to those burrows described by Smith and Crimes (1983) as echinoid burrows (Subphyllochorda); however, the Ocala specimens lack the detail necessary to make a more positive identification.

Large and small tubes are commonly found in the rocks containing Communities I and III, which are typified by sand-dwellers of large and small size. Small tubes only are found in the rocks containing Community II, which are characterized by small echinoid species (see definition of Communities below). If these tubes are preserved echinoid burrows, then their stratigraphic distribution with respect to size and abundance correlates well with the stratigraphic distribution of the spatangoids.

These tubes lack whole or broken echinoid tests, but Ernst *et al.* (1973) stated that many modern spatangoids leave their burrows before dying. One specimen of *Eupatagus antillarum* was found attached to the end of a tube, but it is not certain if the echinoid was in a life position, although the tube was horizontally oriented, as most are, an indication that the echinoid was in a life position. This observation, the shape and structure of the tubes, and their stratigraphic distribution certainly imply that these tubes may be preserved echinoid burrows.

The substrate affinity of the clypeasteroids is based on functional morphology and modern analogues. They lack fascioles, which profoundly affect their burrowing habits. *Periarchus floridanus* (Clypeasteroida) is a large, flat, circular sand dollar, commonly 70-115 mm in diameter. *Wythella eldridgei* Twitchell (Clypeasteroida) is a smaller, elongated sand dollar ranging in test length from 10 to



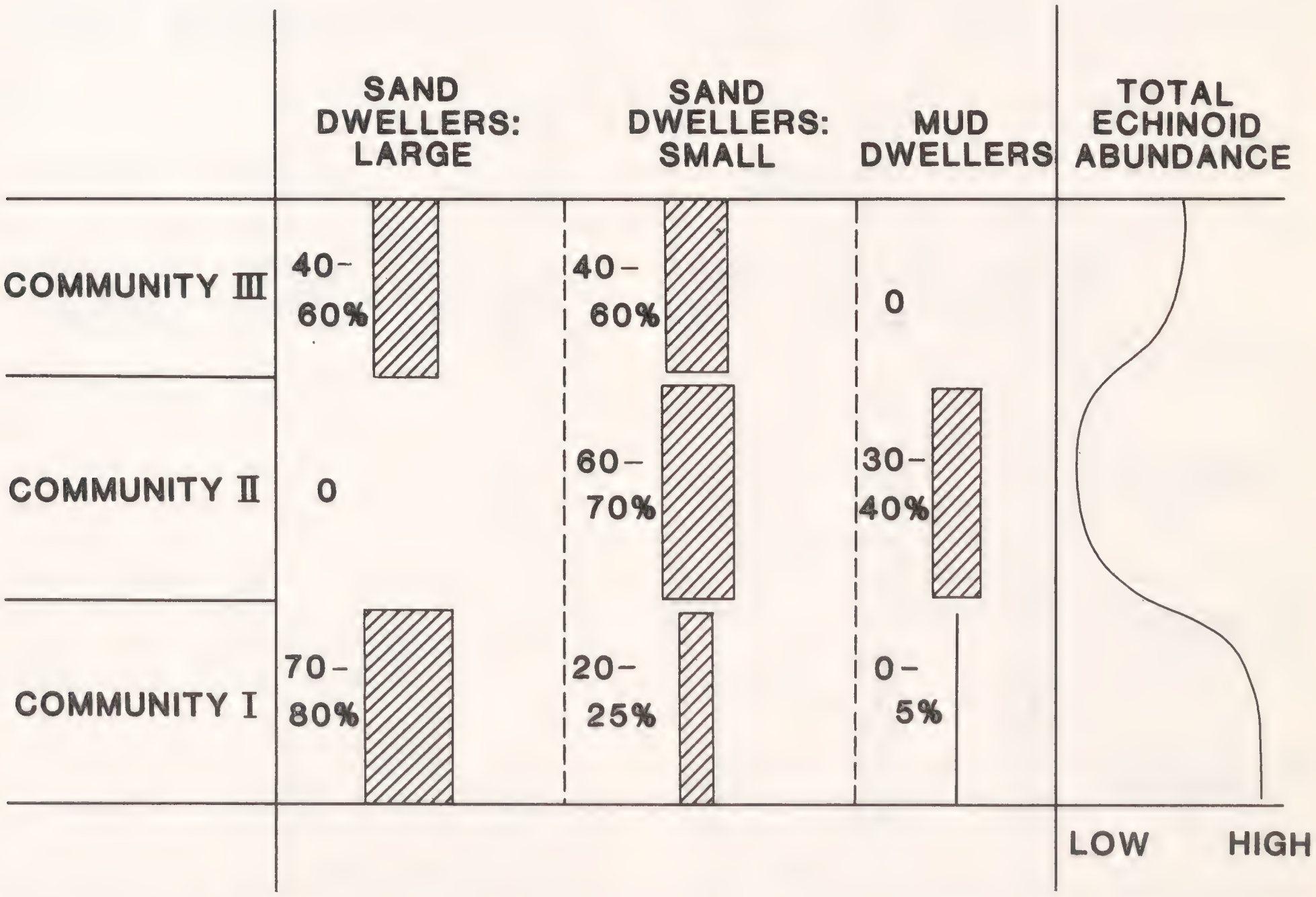
Text figure 9. Stratigraphic range and abundance of 15 Ocala Limestone echinoid species with respect to their burrowing affinities and Communities I, II, and III. The zonation of Zachos and Shaak is also shown.

85 mm. Modern sand dollars, such as *Leodia, Mellita,* and *Encope,* which are morphologically similar to *P. floridanus* and *W. eldridgei,* burrow about 5 mm deep into the sand (Clark, 1910; Goodbody, 1960; Kier, 1965; Kenk, 1944; Hyman, 1958; Pearse, Hum, and Wharton, 1942). Burrowing sand dollars generally do not live in muddy substrates as the flow of water through fine-grained muddy sediments is restricted by the low permeability of the mud. Without the flow of fresh oxygenated water over the petaloid area the echinoid would die from lack of oxygen. It is probable *P. floridanus* and *W. eldridgei* burrowed into sand, just beneath the sediment surface, much like their modern counterparts.

The neolaganids (Clypeasteroida) of the Ocala Limestone are represented by *Durhamella, Neolaganum, Weisbordella,* and *Wythella.* The external morphology of the neolaganids is similar to that of the laganids (Clypeasteroida), with the primary difference lying in the plate arrangement of the coronal system (Durham, 1954). The laganids live in sandy substrate (Hyman, 1955), and it seems reasonable that the neolaganids lived in a similar manner. These small sand dollars probably burrowed several mm below the sediment surface.

Modern cassiduloids live on a sandy substrate (Kier, 1962; Durham *et al.*, 1966). In feeding cassiduloids and holectypoids carry sediment particles to the peristomal depression using suckered tube feet. They do not possess tube feet with prehensile grips capable of secreting mucus as do the spatangoids. Disc diameter of the tube feet restricts the cassiduloids to sand and gravel substrates (Smith, 1980). Kier (1975) and Mortensen (1948) reported *Cassidulus* living on a sandy substrate; it is assumed that all species of *Cassidulus* found in the Ocala also lived on a sandy substrate.

The conditions preferred by *Oligopygus* and *Fibularia* are uncertain. *Echinoneus,* a modern genus morphologically similar to *Oligopygus,* has been observed living under rocks and in areas of coarse sand (Kier, 1965). Fibularids (Clypeasteroida)



Text figure 10. Percentage of mud dwellers, and sand dwellers, large and small in Communities I, II, and III. Total echinoid abundance for each community is shown.

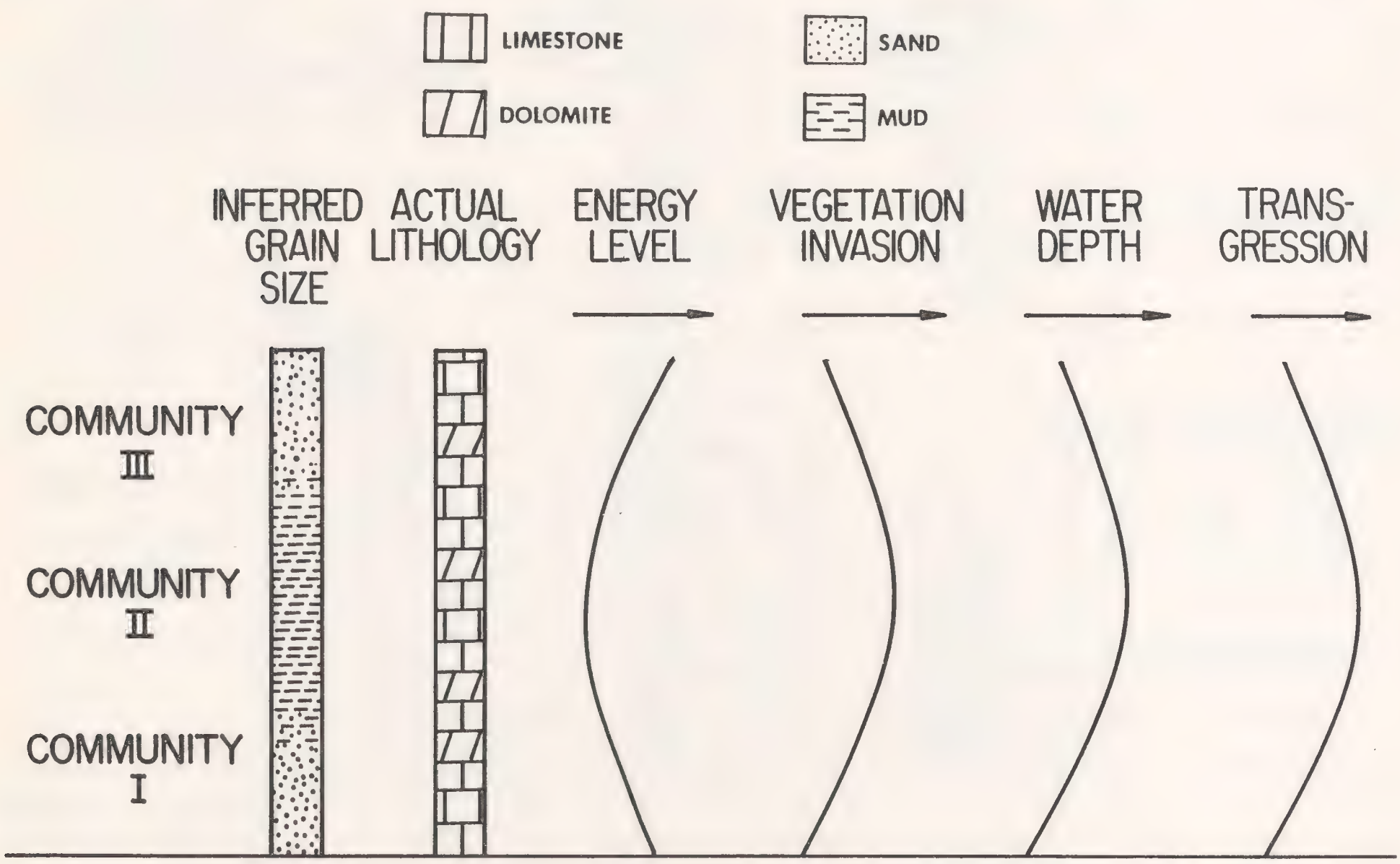
have been reported living in coarse sand (Mortensen, 1948). Most holecypoids are restricted to sandy substrates for reasons mentioned above.

Definition of Communities

Text-fig. 9 lists some of the more common echinoid species of the Ocala Limestone with respect to their substrate affinity. Their stratigraphic distribution is also shown. *Eupatagus antillarum, Periarchus floridanus, Cassidulus globosus* Fischer, and *C. ericsoni* Fischer are restricted to the lower third of the Ocala *(Oligopygus phelani* biozone). Three of these species, *E. antillarum, P. floridanus,* and *C. globosus* are sand-dwellers of large size; *C. ericsoni* is a sand-dweller of small size. These four species define and dominate Community I. The total echinoid abundance of Community I is high (Text-fig. 10).

Five species, *Paraster armiger, Wythella eldridgei, Plagiobrissus dixie, Cassidulus conradi* (Conrad), and *C. trojanus* Cooke are restricted to the upper part of the Ocala *(Oligopygus wetherbyi* biozone). *Paraster armiger, W. eldridgei, P. dixie,* and *C. conradi* are large echinoid species with an affinity for a sandy substrate; *C. trojanus* is a sand-dweller of small size. Although there appears to be a discrepancy in the substrate affinity of *P. armiger,* the abundance of *W. eldridgei, C. conradi,* and *C. trojanus* clearly indicate a sandy substrate. *Paraster armiger* is not nearly abundant as the known sand-dwelling echinoids in this interval of rock, suggesting perhaps they were mud-dwellers. These five species define and dominate Community III, which is characterized by an abundant echinoid fauna, but not quite as abundant as Community I (Text-fig. 10).

Community II is less rigorously defined than Communities I and III. There are no abundant echinoid species found in Community II, as the total echinoid abundance of Community II is considerably less than that of either Communities I and III (Text-fig. 10). Community II is comprised of echinoids that can tolerate a muddy substrate as well as sand-dwellers of small size (Text-fig. 10). There are no large echinoids with an affinity for a sandy substrate present in the rocks containing Community II. The mud-dwellers present in the strata containing Community II are *Agassizia*



Text figure 11. Inferred grain size of the rocks containing Communities I, II, and III, and the interpretation of those grain sizes (see text).

clevei, *Schizaster ocalanus*, and *Brissopsis steinhatchee*. *Agassizia clevei* also occurs in the rocks containing Communities I and III, but the remaining two mud-dwelling species are restricted to the strata containing Community II. In summary, Community II is defined as that fauna composed of the three mud-dwelling echinoid species, the sand dwellers of small size, and lacking the large echinoid species with a preference for sandy substrate.

Text-fig. 10 also shows a total echinoid abundance curve for the three communities recognized in the Ocala Limestone. The difference in the peak abundance of the echinoids in either Communities I or III, compared to Community II, is overwhelming.

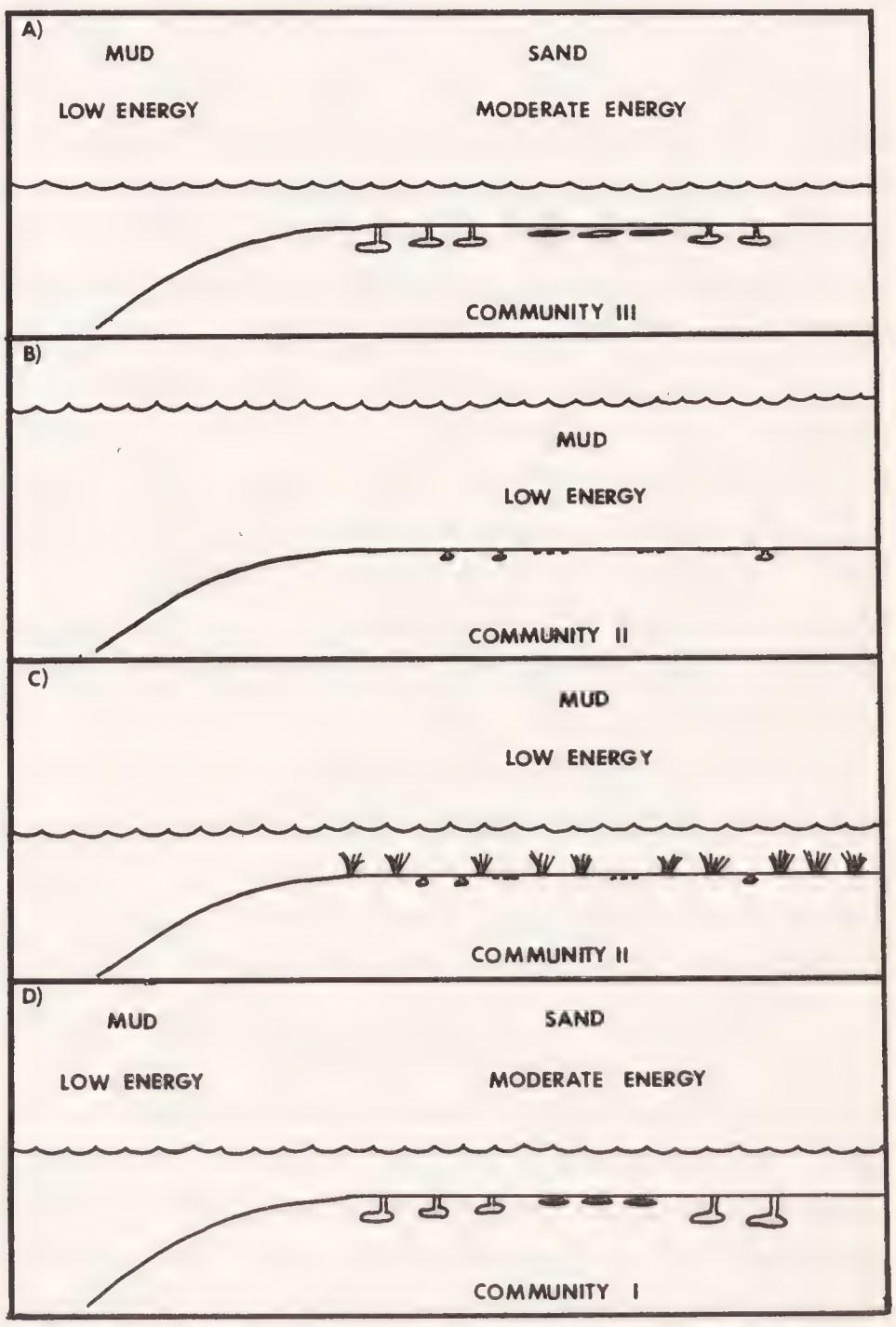
The beds containing Community I display the highest total echinoid abundance of any community. The average number of echinoid specimens per square meter in the rocks containing Community I varies from several to as many as 25. The beds containing Community II display the lowest total echinoid abundance of any community. In the beds containing Community II echinoid specimens are often quite difficult to find. The echinoid abundance is approximately 0.03 specimens per square meter of rock. The abundance of echinoids in the beds containing Community III is close to that of Community I, but slightly less, averaging approximately 1-5 specimens per square meter of rock.

It is essential to note that in benthic communities organisms commonly display a patchy spatial distribution. Consequently, the abundance of specimens for any community as given above may vary considerably between outcrops. As a result, all species representative of any stratigraphic interval in Text-fig. 2 may not be found at every outcrop representing the respective stratigraphic interval. This is especially true of the rocks containing Community II, where echinoid abundance is low.

Interpretation of Communities

The three echinoid communities of the Ocala Limestone contain three major types of echinoids; 1) large echinoids with an affinity for a sandy substrate, 2) small echinoids with an affinity for a sandy substrate, and 3) echinoids with an affinity for a muddy substrate. Based on the stratigraphic distribution of these three echinoid groups it is possible to draw inferences about sediment grain-size at the time of deposition of the Ocala Limestone.

The Ocala was deposited in a relatively pure carbonate environment, and an understanding of substrate compositions in such environments is essential when analyzing grain-size distribution. In modern carbonate environments there is *in situ* accumulation of clay- to sand-sized particles of biogenic origin. Therefore, the sediment grain-size is not totally a function of water energy conditions, but also partially a function of the type and size of a biogenic material being produced *in situ*. Low water energy environments are characterized by clay, silt, sand, and even



Text figure 12. Interpretive model of the Floridian carbonate bank during Late Eocene.
a) Community III.
b) Community II, deeper water model.
c) Community II, vegetation model
d) Community I.

larger sized particles. Increasing water energy conditions result in a winnowing of the fine-grained material first, leaving behind the larger grains. Beyond a critical water energy level relatively pure, sand-sized carbonate substrates can be formed.

Community I is dominated by sand-dwelling echinoids of large size (Text-fig. 10), indicating that the substrate was originally composed of sand-sized grains (Text-fig. 11). Community II is characterized by low echinoid abundance, the absence of large echinoids with an affinity for a sandy substrate, and a high percentage of mud-dwelling echinoids (Text-fig. 10), implying that the sediments contained a large percentage of mud (Text-fig. 11). Fine suspended mud tends to clog the water vascular system of the echinoids and few echinoid species are adapted for such environments (Ernst and Siebertz, 1977). However, there must have been appreciable amounts of sand (or possibly silt) present in the substrate to have sustained the sand-dwelling echinoids of small size. This is to be expected in a carbonate environment, due to the *in situ* accumulation of biogenic material of varying sizes. Community III is similar to Community I in that it is composed predominantly of large echinoids with an affinity for a sandy substrate. The total echinoid abundance is slightly less than that of Communnity I, but much greater than that of Community II. The sediments at the time of occurrence of Community III are inferred to have been predominantly of sand-size (Text-fig. 11).

The echinoid distribution in the Ocala Limestone indicates a change from predominantly sand-sized grains near the base to predominantly mud in the middle to predominantly sand-sized grains at the top. The changes in relative abundance and size of the individual echinoid species imply the shift in grain-size were gradational. The faunal transition in the rocks containing Communities I, II, and III is not sharp, but gradational. The sand-dwellers of larger size in Community I gradually decreases in abundance upsection until they disappear. The sand-dwellers of large size in Community III decrease in abundance downsection until they eventually disappear. The precise boundaries between Communities I and II, and II and III are the last and first occurence, respectively, of the sand-dwellers of large size.

In a general sense, the test size of the sand-dwellers of Community I decreased upsection. Likewise, the test size of the sand-dwellers of Community III decreases downsection. This is to be expected, as the presence of mud in the substrate restricts the growth of the sand-dwellers and the greater the proportion of mud in the substrate, the smaller the test of sand-dwelling echinoids (Nichols, 1959).

The changes in grain-size between substrates of the three communities of the Ocala Limestone can be attributed to changes in the water energy level at the time of deposition (Text-fig. 11). Communities I and III represent higher water energy conditions than Community II. This change in water energy conditions may be attributed to either a change in water depth at the time of deposition, or to an invasion of some type of vegetation, such as turtle grass (Text-fig. 11).

The presence of vegetation would slow water currents (decrease water energy level) at the sediment-water interface, and in effect, trap fine-grained material being carried in suspension. This is assuming high enough water energy conditions were initially present to carry material in suspension. If vegetation were to have reached its peak abundance during the occurrence of Community II, then the substrate would be expected to be composed of a large percentage of mud (Text-fig. 11). A subsequent decline in vegetation abundance would have allowed the formation of a sandy substrate, assuming that high enough water energy conditions were present.

An alternate hypothesis to explain the change in water energy level is a change in water depth. In general, the deeper the water, the lower the water energy level. Therefore, water depth would have been deeper during the occurrence of Community II that that of Communities I and III (Text-fig. 11).

Toulmin (1977) considers the Moodys Branch Formation in the eastern Gulf Coast to be a transgressive unit. The Moodys Branch Formation correlates with the lower Ocala Limestone (Croft, 1980). The fluctuations in the cheilostome bryo-

zoan fauna reflect deepening water during Early and Middle Jacksonian deposition and shoaling in Late Jackson deposition (Cheetham, 1963). Consequently, it is probable that the distribution of echinoids in the Ocala is also a function of changing water depth during deposition. It seems likely that a transgressive-regressive sea was responsible for the changing water depths during deposition of the Ocala Limestone.

The distribution of molluscs in the Ocala Limestone support the conclusions based on the analysis of the echinoid fauna. The molluscs (gastropods and pelecypods) reach their highest abundance in the rocks containing Communities I and III, with oysters being common. This observation implies a nearshore, shallow water, marine environment. The rocks containing Community II are characterized by relatively lower molluscan abundance, suggesting deeper water.

Depositional textures including grainstones, packstones, and wackestones can be recognized in the Ocala Limestone. The rocks containing Communities I and III are generally classified as grainstones and packstones, which grade into wackestones in the beds containing Community II. There are no definitive boundaries between these rock types, as all contacts are gradational. In addition, diagenesis and solution have caused local alteration. The present rock types infer changing water energy conditions at the time of the deposition; that is, lower water energy levels in the middle of the Ocala. This observation is consistent with conclusions reached from paleontological observations.

Oligopygus seems to have no preference for the different substrate types that occurred during deposition of the Ocala Limestone.. Although each species of *Oligopygus* in the Ocala is generally restricted to a single Community, there are no significant morphological changes between species that would give preference to a different type of substrate. The specific changes within the genus are probably due to phylogeny rather than ecology; therefore, *O. phelani*, *O. haldemani*, and *O. wetherbyi* represent a time-evolutionary lineage.

V. PALEOGEOGRAPHY

There are few regular echinoids preserved in the Ocala Limestone, during this study less than ten specimens were found. Spines from regular echinoids are often found, but are not abundant. In modern environments, regular echinoids live in the higher water energy nearshore area, whereas heart urchins (spatangoids) and sand dollars (clypeasteroids) commonly live further offshore where the water energy level is relatively low. The absence of abundant regular echinoids in the Ocala implies the absence of a high water energy environment in the littoral zone, suitable to habitation by the regular echinoids and it may be inferred that the slope of the local continental shelf was quite gentle. This is compatible with a carbonate bank environment as suggested by Cheetham (1963). Text-fig. 12 schematically depicts a hypothetical profile across the northern margin of the bank at the time of deposition (Late Eocene). The water depth is uncertain, but probably never exceeded more than 50 meters (Cheetham, 1963).

The total geographic extent of the carbonate bank during the Late Eocene is uncertain. The entire outcrop area of the Ocala Limestone was certainly a part of the bank, as evidenced by the abundant assemblages of echinoids, bryozoans, and molluscs, typical of the bank. The lateral extent of these faunas into the subsurface is unknown. The northern edge of the bank was truncated by the Suwannee Straits (Cheetham, 1963); the southern, eastern, and western extent of the bank during Late Eocene are unknown.

Modern Faunal Analogue

Kier and Grant (1965) reported the occurrence of an echinoid fauna from the Key Largo Reef Preserve similar to that found in Communities I and III. *Encope michelini* Agassiz, *Leodia sexiesperforata* (Leske), *Meoma ventricosa* (Lamark), and *Plagiobrissus grandis* live in the upper layer of clean, grassless sand comprising the inter-reef deep channel, located behind the main reef-crest. They are frequently found living together in the channel. It should be emphasized that there are

no biohermal structures preserved in the Ocala Limestone; however, the Ocala echinoid fauna and the Key Largo echinoid fauna are quite similar with respect to substrate affinity, as well as general test morphology. Water depth in the Recent channel is shallow (less than 15 meters) and it is probable that environmental conditions (*i.e.*, substrate, salinity, water energy level) were similar during deposition of the Ocala Limestone.

VI. ACKNOWLEDGMENTS

Acknowledgment is made to the donors of the Petroleum Research Fund administered by the American Chemical Society for support of this research. We thank Louis Zachos for sharing his expertise on Cenozoic enchinoids. We thank Ramil Wright for his insight. We also acknowledge the Department of Geology, Florida State University, Tallahassee and the Florida State Museum, University of Florida, Gainesville for financial and moral support. Lastly, we thank Porter Kier and Norris Williams for reviewing an earlier draft of this manuscript.

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REVIEWS

SUBURBAN GEOLOGY: An Introduction to the Common Rocks and Minerals of Your Back Yard and Local Park, by Richard Headstrom. Published by Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1985, xvii + 136 pp., illus., paperbound, $8.95

This is the third volume in a suburban trilogy, the first two being *Suburban Wildlife* and *Suburban Wildflowers;* all designed for the amateur naturalist. This small book is clearly designed for the museum sales counter and is fairly well suited for that market, especially for the younger visitor who has only a casual interest in the subject. A clue to the reason for generating this series can be perceived in the author's position as a museum curator and as a consultant for the nature programs of the Boy Scouts and Girl Scouts. The book cannot be of interest to the experienced geologist or rock collector, and this reviewer finds it somewhat overpriced for its slender size and the very sketchy treatment of rocks and minerals.

EXPLORING THE OCEANS: An Introduction for the Traveler and Amateur Naturalist, by Henry S. Parker. Published by Prentice-Hall, Inc., Englewood Cliffs, New Jersey, 1985, xiv + 354 pp., illus., index, paperbound, $15.95

This book is from the pen of an experienced biologist/university faculty member/former U.S. Navy diver. As such, it is much more scholarly and authoritative than the previous reviewed volume (see above). Also designed for the amateur naturalist and traveler, this book is reasonably comprehensive and informative about such topics as marine biology and geology, plate tectonics, ocean chemistry, ocean climate and circulation, and life in the seas. The metric table and conversion factors and the outlined taxonomic classification of marine organisms in the appendix are most useful. An index is included. This volume is recommended; it is reasonably comprehensive and authoritative without being tedious or too involved for the amateur reader.

—H.C.S.

REVIEWS

PALEOBOTANY, PART I: Precambrian Through Permian, edited by Thomas N. Taylor and Edith L. Smoot. A Hutchinson Ross Benchmark Book, published by Van Nostrand Reinhold Company, Inc., New York, New York, 1984, xvii + 409 pp., illus., cloth, $50.00

PALEOBOTANY, PART II: Triassic Through Pliocene, edited by Thomas N. Taylor and Edith L. Smoot. A Hutchinson Ross Benchmark Book, published by Van Nostrand Reinhold Company, Inc., New York, New York, 1984, xv + 364 pp., illus., cloth, $45.00

The several Benchmark series present selected anthologies of papers or journal articles from the scientific literature on various subjects or phases of scientific research, reprinted with an introduction to each volume and, in addition, scholarly commentaries on each paper or each group of "benchmark papers" by the editor(s). A number of volumes in the distinguished series of Benchmark Papers in Geology, edited by Rhodes W. Fairbridge, have been reviewed in these pages. The present volumes are from the series Benchmark Papers in Systematic and Evolutionary Biology.

In recent years, enormous advances in the knowledge of ancient plant remains have been made as research efforts have been turned toward the neglected sparsely fossiliferous rocks of the Cryptozoic and early Phanerozoic. Many "unfossiliferous" sequences have been found to contain from significant traces to abundant and beautifully preserved microfloras when subjected to close examination. Thus, it is not surprising to note that most of the collected papers in these anthologies are dated (first publication) after 1960.

These two volumes, arranged chronologically by geological subject, comprise an important overview of the scope and stratigraphic distribution of paleobotanical remains through the rock column. It is made more valuable by the commentaries and explanatory notes contributed by the editors to each stratigraphic subdivision, summarizing and evaluating the state of knowledge of the botanical content of the strata from each segment of geologic time with comments on the individual papers and an appended reference list to document their comments and provide additional direction to the reader for further investigation in each subject area.

These two volumes are a valuable addition to the benchmark anthologies and are highly recommended as a handbook illustrating the present state of knowledge in stratigraphical paleobotany.

GEOLOGY AND PALEONTOLOGY OF SOUTHEAST ASIA, Volume 24, edited by Teiichi Kobayashi, Ryuzo Toriyama, and Wataru Hashimoto. Published by University of Tokyo Press, Tokyo, 1982, vii + 242 pp., illus, tbls., atlas of 19 plates, cloth, $59.50

This, the twenty-fourth volume of the series begun in 1964, comprises seven articles by thirteen authors from the Philippines and Japan. Two articles are on the paleontology of Thailand, and five are on the Philippines; the last is a lengthy supplement to the Paleontology of the Philippines, 1969-1981. Among the contents are reports on an Upper Permian fusuline fauna from North Thailand, Middle Permian corals from Central Thailand, two papers on the larger foraminifera from the Philippines, and two articles on molluscan faunas from Central Luzon. Taxonomic descriptions include nine new species: one Permian foraminifer, two Permian corals, five Tertiary bivalves, and one new Tertiary gastropod. This book, similar to the previous volumes in this series, is beautifully illustrated, informative, and a valuable addition to the knowledge of Southeast Asian geology and paleontology.

—H.C.S.

OBSERVATIONS AND RECOMMENDATIONS ON THE FOSSIL DINOCYST GENERA *CTENIDODINIUM, DICHADOGONYAULAX,* AND *KORYSTOCYSTA*

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AMOCO PRODUCTION COMPANY
NEW ORLEANS, LOUISIANA

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I. ABSTRACT

The fossil dinocyst genus *Dichadogonyaulax,* erected by Sargeant in 1966, has proven to be very controversial. It has been synonymized with *Ctenidodinium* at least twice and resurrected at least twice. The separation of the two genera was based on the equal development of paracingular ornamentation in *Dichadogonyaulax* and the unequal development of those features in *Ctenidodinium.* This paracingular differentiation is a somewhat variable feature and probably not of generic significance.

There is, however, a fundamental difference in the paratabulation of the epicyst between representatives of the two genera. The type species of *Ctenidodinium, C. ornatum,* exhibits a preapical paraplate separating the second and fourth apical paraplates and also possesses anterior intercalary paraplate(s); whereas the type of *Dichadogonyaulax, D. culmula,* either has no preapical paraplate or it is reduced and displaced toward the ventral surface, thus allowing contact between the second and fourth apical paraplates. No anterior intercalary paraplates are present in *D. culmula.*

Korystocysta, erected by Woollam in 1983, has a *Ctenidodinium* style epicystal paratabulation and differs from *Ctenidodinium* in having an abbreviated apical horn and accessory parasutural ("growth bands") ridges.

II. INTRODUCTION

The generic differentiation of paratabulate gonyaulacoid dinocysts with epicystal archeophyles has proved to be troublesome for many palynologists. In fact, the differentiation of species within this complex is frequently easier than deciding in which genus the species fits. This situation is a result of the two principal genera, *Ctenidodinium* and *Dichadogonyaulax,* being separated on the unequal *versus* equal development of paracingular ornamentation. This feature has been regarded as not having generic significance by some workers (Lentin and Williams, 1973; Stover and Evitt, 1978) and by others as *the* major generic criterion (Sargeant, 1966, 1975; Wollam, 1983). The relative de-

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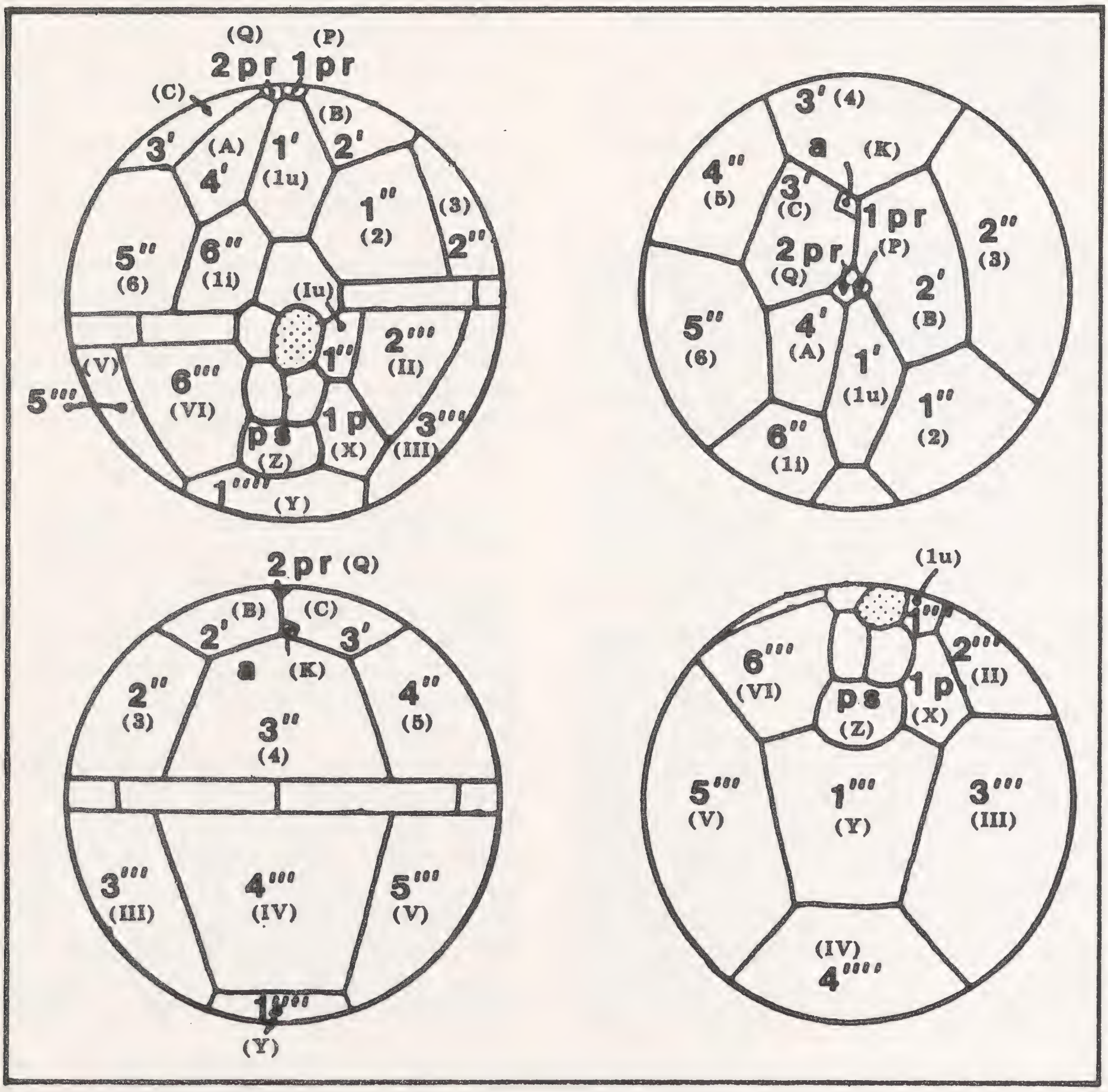
velopment of ornamentation on the anterior and posterior paracingular margins is a variable feature, virtually impossible to discern in highly compressed specimens, and seems to me to be not the sort of morphologic feature that should be utilized to separate dinocysts at the generic level.

The paratabulation of the various species in this complex generally has been accurately recorded in the literature, if not by the first worker, then by further study and/or emendation. Upon initial examination, it emerges that both *Ctenidodinium* and *Dichadogonyaulax,* as currently circumscribed exhibit as paratabulation of: 0-3pr, 4′, 0-2a, 6″, 6c, x-6s, 6‴, 1p, 1⁗ (Woollam, 1983). Further study of numerous specimens, however, has demonstrated that a means of separating *Ctenidodinium* and *Dichadogonyaulax* exists, that being the epicystal paratabulation. It is the intent of this paper to demonstrate the evidence to support the utilization of epicystal paratabulation as a means of separating the two previously mentioned genera and to briefly discuss and emend *Korystocysta.*

The principal sources for the dinocysts illustrated herein are core and cutting samples of wells from the Gulf and Atlantic coastal plain. In addition, some outcrop



Text Fig. 1 Diagrammatic representation of a gonyaulacoid dinocyst in: A) ventral view, B) apical view, C) Dorsal view, and D) antapical view comparing Kofoidian paraplate notation (boldface) of major paraplate series with the Taylor (1980) notation (parentheses).

samples from classic British and European localities were examined. The type material for *Ctenidodinium chondrum* was supplied to the author by Warren Drugg. The type material for *C. scissum* (McIntyre and Brideaux, 1980) was supplied by the I.S.P.G. of Calgary. Their assistance in this study is gratefully acknowledged. Illustrated specimens are stored at Amoco Production Company in New Orleans, Louisiana (U.S.). Specimens are located by reference to the lower left corner of the coverslip, with label at observer's left, in millimeters to the right (R) and away (+) from the observer.

III. ACKNOWLEDGMENTS

The author would like to thank Amoco Production Company for permission to publish this work. The assistance of Sue Evans for drafting and Jim Truehart for photographic work was invaluable. Thanks also go to Jeff Stein and Sue Duffield who read earlier versions of the manuscript. In addition, informal discussions with Dan Beju and David Wall were helpful in consolidating the thoughts expressed herein, although the views expressed are the author's alone.

IV. DISCUSSION

All paratabulation information in this paper uses Kodoidian notation. Text figure 1 provides a comparison of major plate series using Kodoidian notation with the newer notation of Taylor (1980) being used by some authors.

The dinocysts comprising the *Ctenidodinium* "complex" are gonyaulacoid cysts, which exhibit differences in epicystal paratabulation. The epicystal paratabulation of *C. ornatum,* the type species, and its close relative *C. combazii* is 1pr, 4′, 1-2a, 6″ (Pl. 1, figs. 1, 2). The paraplate topologic arrangement is also significant when comparing those forms in the *Ctenidodinium* "complex." The preapical paraplate is located at the apex, thus separating the second and apical fourth paraplates (Pl. 1, figs. 1, 2; Pl. 2, figs. 1-3). This arrangement also exists in the species assigned to *Korystocysta* (Pl. 1, figs. 3, 11, 12).

Examination of the epicystal paratabulation of the type species of *Dichadogonyaulax, D. culmula* (Pl. 3, fig. 1) reveals a paratabulation of 1pr, 4′, 0-a, 6″. In addition to the absence of the anterior intercalary paraplates, the location of the preapical paraplate is significant. The preapical paraplate is displaced posteroventrally, thereby allowing contact between the second and fourth apical paraplates (Pl. 3, fig. 1). The displacement of the preapical paraplate, which appears to be a result of shortening the first apical paraplate, is also seen in *D. pannea* (Pl. 1, fig. 10), *D.* cf. D. *culmula* (Pl. 1, figs. 4 and 7), and *Dichadogonyaulax* sp. B (Pl. 1, figs. 5-9).

I, therefore, propose to separate *Dichadogonyaulax* from *Ctenidodinium* on the basis of the posteroventral displace-

TABLE I

MORPHOLOGIC FEATURE / GENUS	PREAPICAL PARAPLATE(S)	APICAL PARAPLATE TOPOLOGY	ANTERIOR INTERCALARY PARAPLATES	PARACINGULAR ASYMMETRY	ACCESSORY RIDGES	APICAL HORN
Ctenidodinium	1-2 Paraplates	2′ & 4′ Separated By Preapicals	1-2 Paraplates	Generally Yes, But Variable	Not Generally Present	No
Dichadogonyaulax	0-1 Displaced Posteroventrally	2′ & 4′ In Contact	Absent	Generally Not, But Variable	No	No
Korystocysta	1-2 Paraplates	2′ & 4′ Separated By Preapicals	1-2 Paraplates	No Asymmetry In Documented Forms	Yes	Yes Size Varies

A summary of the key morphologic features for generic separation of *Ctenidodinium*, *Dichadogonyaulax*, and *Korystocysta*.

ment of the preapical paraplate, which allows contact between the second and fourth apical paraplates. Although *D. culmula* and *D. pannea* have no anterior intercalary paraplate, the figure of *C. schizoblatum* by Norris (1965, Fig. 4A) indicates the presence of a single paraplate (3′ of Norris) in that position. The figure also illustrates the contact of the second and fourth apical paraplates and a thickened parasuture in the same position as the preapical paraplate in *D. culmula*. Until the type material can be re-examined it appears preferable to retain *schizoblatum* in the genus *Ctenidodinium*.

The hypocystal paratabulation of *Ctenidodinium, Dichadogonyaulax,* and *Korystocysta* is the same in terms of the number of paraplates and topology with minor variations in paraplate shape. The posterior intercalary paraplate is somewhat elongate in *Korystocysta* (Pl. 1, fig. 12) (Woollam, 1983). The antapical paraplate of *Dichadogonyaulax* and *Ctenidodinium* is slightly asymmetric with the long side pointing toward the sixth postcingular paraplate (Pl. 1, figs. 6, 9; Pl. 2, fig.4).

The recent study by Helenes-Escamilla (1984) demonstrated strong asymmetry of the antapical paraplate in *Cribroperidinium*. The epicystal arrangement in that genus shows the displacement of the preapical paraplate ("P" of Helenes-Escamilla) in a posteroventral direction, *i.e.*, a situation identical to that in *Dichadogonyaulax*. *Dichadogonyaulax* exhibits a unique combination of morphologic features that serve to distinguish it from its other relatives in the *Ctenidodinium* "complex."

Table I summarizes the key morphologic features I propose to utilize to separate *Ctenidodinium, Dichadogonyaulax* and *Korystocysta*.

V. SYSTEMATIC PALYNOLOGY

Class DINOPHYCEAE Fritsch 1929
Order PERIDINIALES Haeckel 1894

PLATE 1

Figures

1, 2. *Ctenidodinium combazii,* Photomicrograph and *camera lucida* drawing illustrating the anterior intercalary paraplate and the central position of the preapical paraplate. Bar equals 20 μm. P41126A02 S8, R14.4/+5.2, Upper Bathonian, The Fleet, Dorset, England.

3. *Korystocysta kettonensis* (?), Photomicrograph of detached epicyst (operculum) illustrating the paraplate topology. Note the central location of the preapical paraplate and the two anterior intercalary paraplates. Bar equals 20 μm. DNB80/19 Ketton, R12.8/+3.3, Bathonian, Ketton Cement Quarry, England.

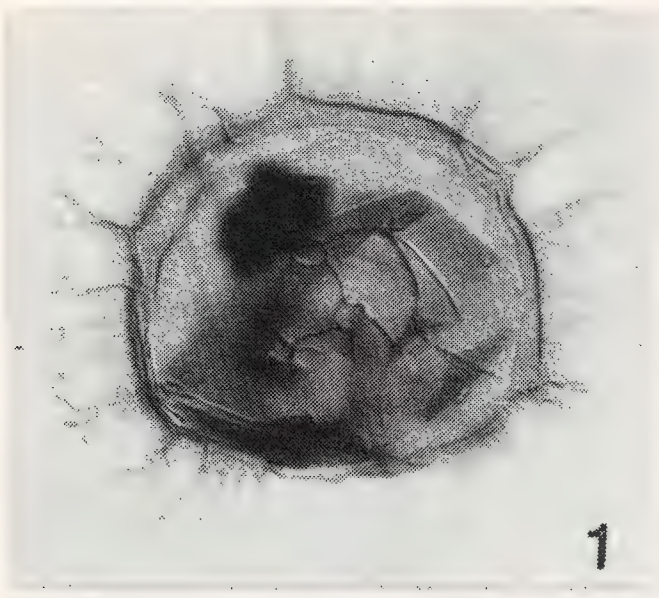
4, 7. *Dichadogonyaulax* cf. *D. culmula,* Photomicrograph and *camera lucida* drawing illustrating the posteroventral displacement of the preapical paraplate and the resulting contact of paraplates 2′ and 4′. Compare with pl. 3, figs. 1, 2. Bar equals 20 μm. P1018C54A, R14.3/+15.8, Upper Jurassic subsurface, Atlantic Coast offshore, U.S.

5, 6. *Dichadogonyaulax* sp. B, Intact specimen, epicyst and hypocyst (interior view) of a lightly ornamented form. Note the slight asymmetry of the antapical paraplate in Fig. 5. Bar equals 20 μm. Upper Jurassic, C.O.S.T. B-3, Atlantic Coast offshore, U.S.

8, 9. *Dichadogonyaulax* sp. B, Intact specimen, epicyst (interior view) and hypocyst of a complexly ornamented form. Bar equals 20 μm. Upper Jurassic, C.O.S.T. B-3, Atlantic Coast offshore, U.S.

10. *Dichadogonyaulax pannea,* Detached epicyst (interior view) showing the contact between paraplates 2′ and 4′. Bar equals 20 μm. PL2330/1; R2.7/+14.6, Middle Tithonian, Pallasioides Zone, Littleton Brick Pit, Wheatley, England.

11, 12. *Korystocysta pachyderma,* Lateral views illustrating the two anterior intercalary paraplates and the slightly elongate 1p paraplate. Bar equals 20 μm. P41135B09, R26.9/+22.3, Lower Bathonian, Burton Cliff, England.



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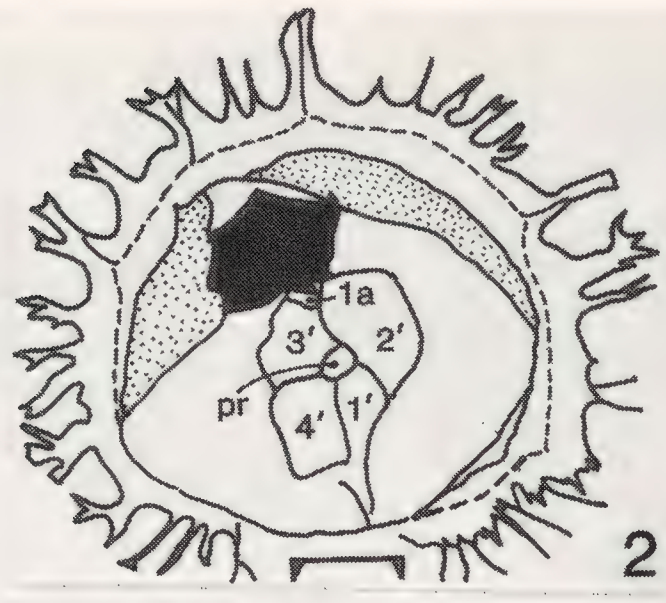

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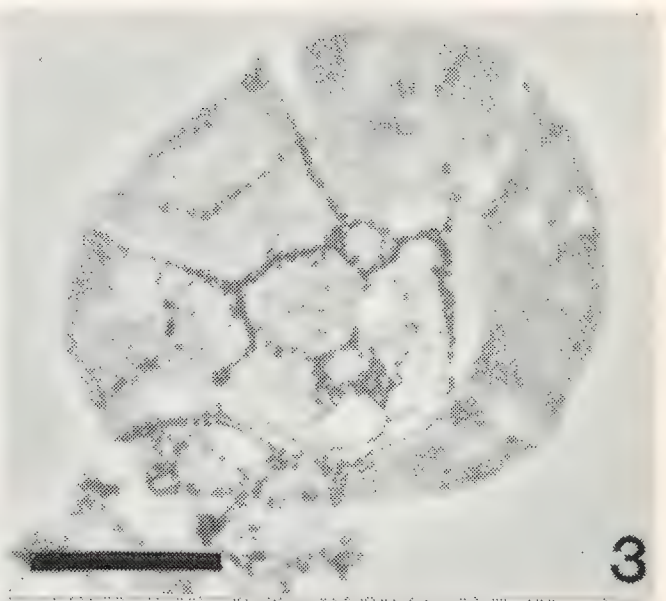

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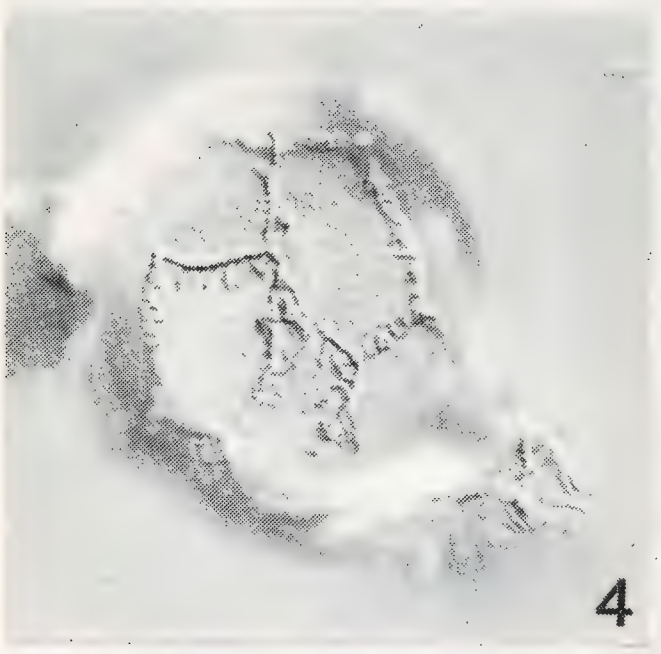

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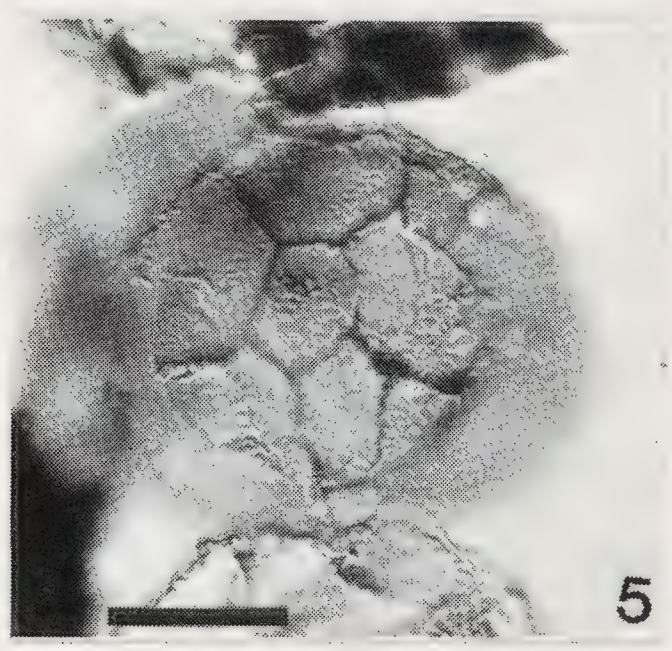

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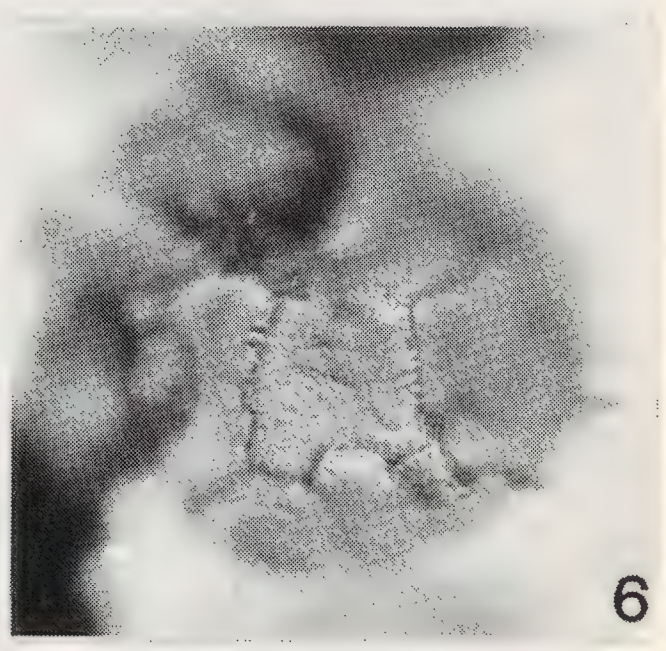

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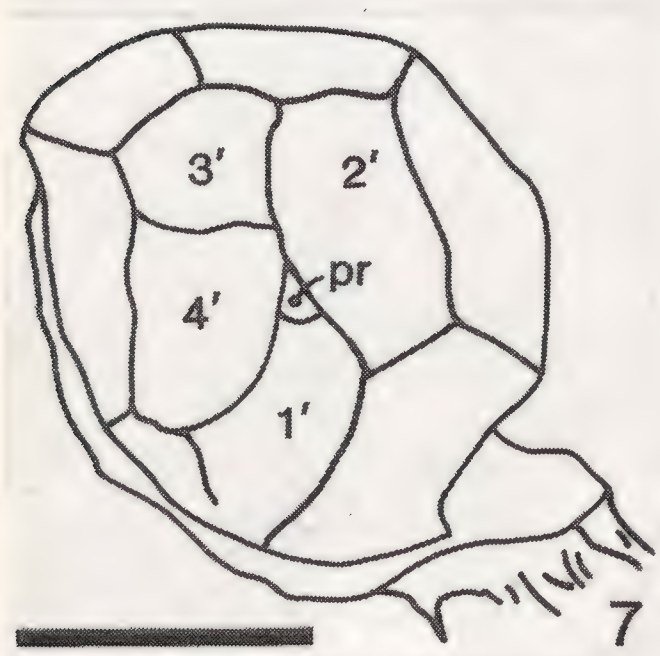

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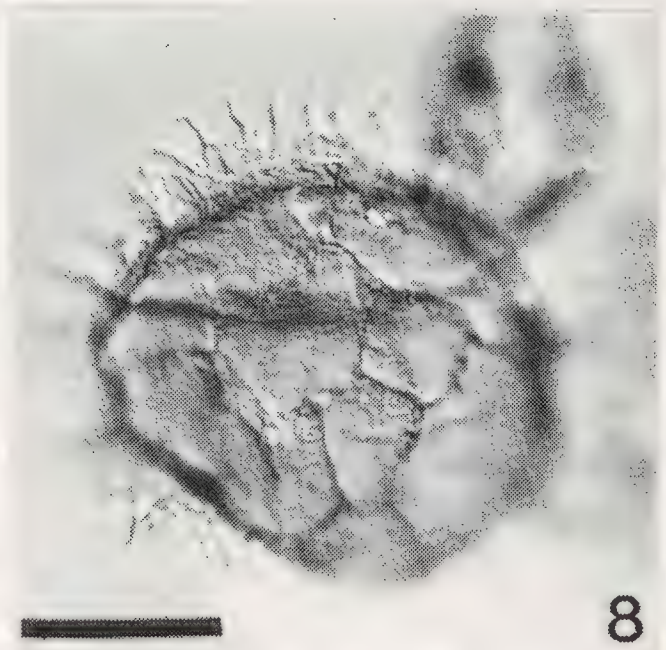

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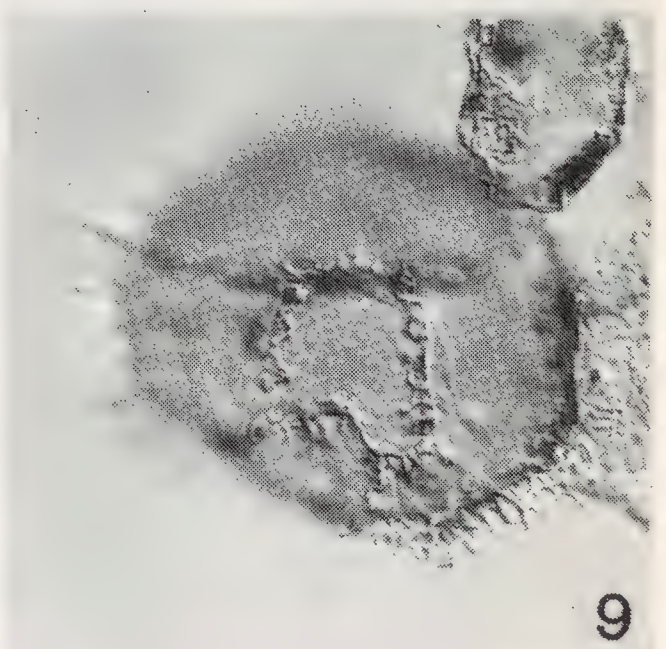

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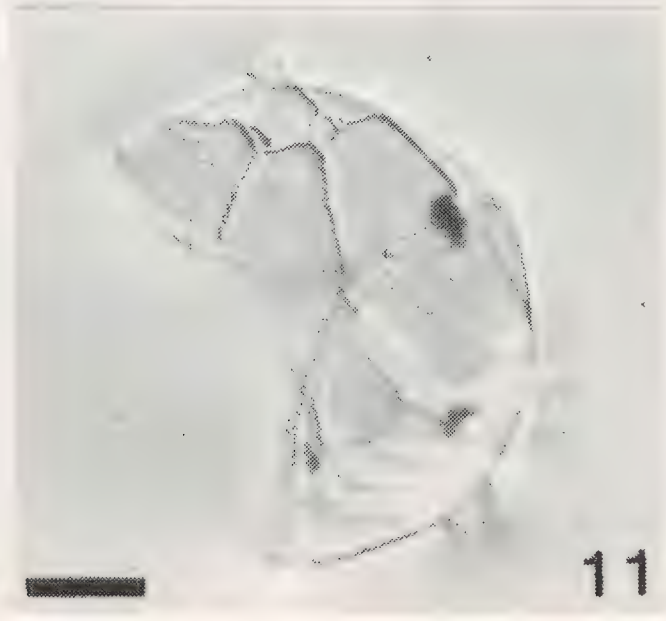

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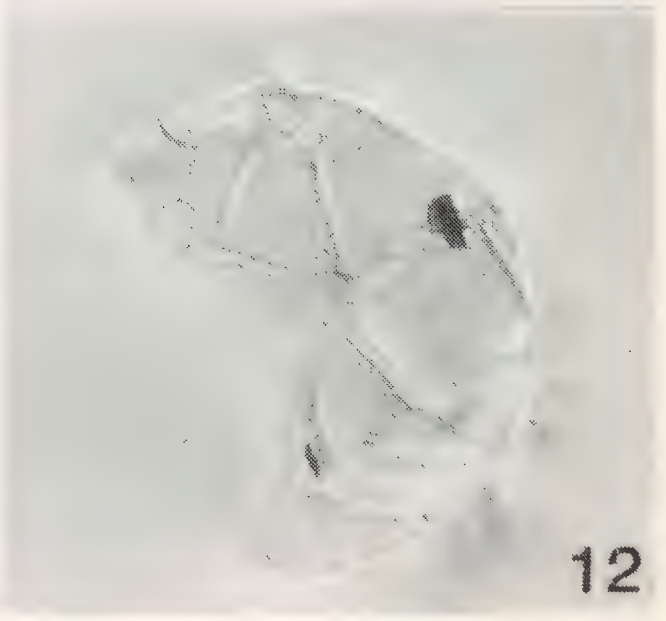

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PLATE 1

Genus CTENIDODINIUM Deflandre 1938 emend.

Synonym: *Brotzenia* Horowitz 1975

Type species: *C. ornatum* (Eisenack 1935) Deflandre 1938

Emended Description: Proximochorate dinoflagellate cysts constructed of an autophragm, subspherical to ellipsoidal in shape, lacking an apical horn. Paratabulation formula: 1-3pr, 4′, 1-2a, 6″, x-6c, 6‴, 1p, 1⁗, x-6s, indicated by parasutural ridges, crests or septa which are generally ornamented with spines. Accessory ridges ("growth bands") generally absent. Combination (epicystal, tprtAtItP, henceforth referred to as Type E) archeopyle, operculum separating from the hypocyst along the posterior margin of the precingular paraplates. Parasutural features on the paracingulum may or may not be reduced on the anterior margin as compared with the posterior margin.

Comparison: Ctenidodinium differs from *Dichadogonyaulax* in possessing one or more preapical paraplates positioned at the apex and anterior intercalary paraplates, from *Korystocysta* in generally lacking accessory parasutural ridges (although see Gocht, 1984, and Pl. 2, fig. 4) and an apical horn, and from *Energlynia* in lacking an antapical horn and having an epicyst and hypocyst of nearly equal size.

Accepted Species:

C. chondrum - Drugg 1978
C. combazii - Dupin 1968
C. continuum - Gocht 1970
C. elegantulum - Millioud 1969
C. ornatum - (Eisenack, 1935) Deflandre 1938
C. sellwoodii - (Sarjeant, 1975) Stover and Evitt 1978
C. tenellum - Deflandre 1938

PLATE 2

Figures

1. *Ctenidodinium chondrum,* Detached epicyst illustrating the paraplate topology. Bar equals 20 μm. P1018C61A, R10/+18.9, Upper Jurassic subsurface, Atlantic Coast offshore, U.S.
2. *Ctenidodinium continuum,* Detached epicyst illustrating the paraplate topology. Bar equals 20 μm. B41135B09, R8.6/+16.5, Lower Bathonian, Burton Cliff, England.
3. *Ctenidodinium tenellum,* Detached epicyst illustrating the paraplate topology. Bar equals 20 μm. P41126A02 S8, R14.5/+16.2, Upper Bathonian, The Fleet, Dorset, England.
4. *Ctenidodinium* cf. *combazii,* Antapical paraplate illustrating accessory parasutural ridges ("growth bands") similar to those described by Gocht (1984). Bar equals 20 μm. P41126A05 S8, R7.3/+13.3, Upper Bathonian, The Fleet, Dorset, England.
5, 6. *Dichadogonyaulax irregulare,* n. sp., Holotype. Hypocyst and epicyst (interior view) of an intact specimen. Note large size of the antapical paraplate and the interrupted parasutural crests. Bar equals 20 μm. P320C66A, R15.7/+9.7, Lower Cretaceous, north Louisiana subsurface, U.S.A.
7. Paratype. An intact, compressed specimen illustrating the large antapical paraplate. Bar equals 20 μm. P280C52A, R19.1/+5.3, Lower Cretaceous, north Louisiana subsurface, U.S.A.
8. Bar equals 20 μm. 64X A33-8, Lower Cretaceous, eastern Louisiana subsurface, U.S.A.
9. Paratype. An intact specimen illustrating the extreme variation in parasutural ornamentation and dissection. Bar equals 20 μm. P280C52A, R15.7/+8.6, Lower Cretaceous, north Louisiana subsurface, U.S.A.
10. Paratype. Interior view of epicyst. Bar equals 20 μm. P280C44A R6.2/+7, Lower Cretaceous, north Louisiana subsurface, U.S.A.
11. Hypocyst. Note dissected parasutural crests and large size of the antapical paraplate. Bar equals 20 μm. 64X A33-6, Lower Cretaceous, eastern Louisiana subsurface, U.S.A.
12. Hypocyst. Note highly dissected parasutural ornamentation. Bar equals 20 μm. P317C29A R1.7/+9.7, Lower Cretaceous, north Louisiana subsurface, U.S.A.

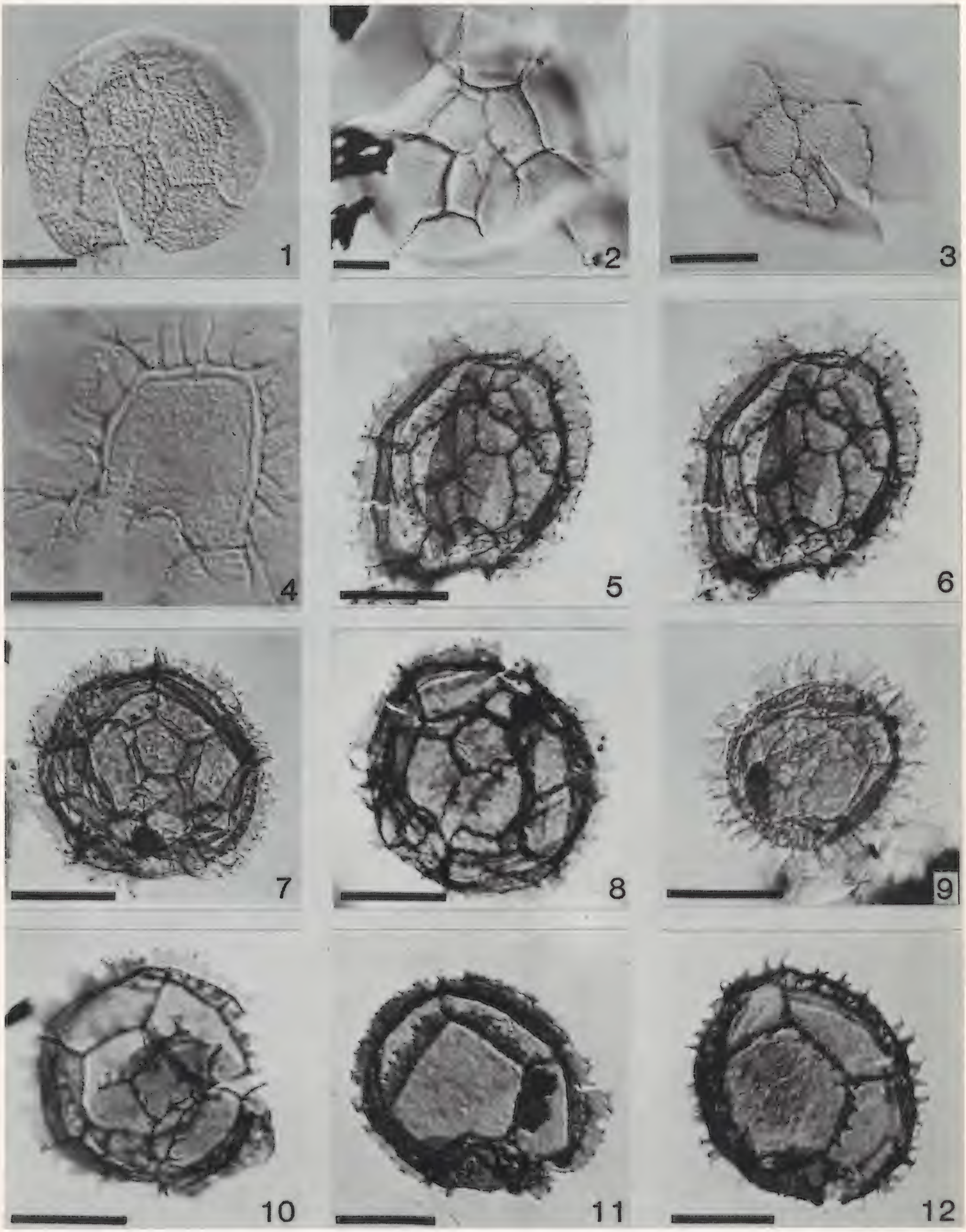


PLATE 2

Provisionally accepted species:

Generally these are species about which questions exist concerning the epicystal paratabulation.

C.? mosaicum - Dodekova 1975
C.? rotundum - Dodekova 1975
C.? schizoblatum - (Norris 1965) Lentin and Williams 1973
C.? scissum - McIntyre and Brideaux 1980
C.? stauromatos - (Sarjeant, 1976) Stover and Evitt 1978. If the number of anterior intercalary paraplates reported by Sarjeant is correct, then this species warrants a new genus.

Genus DICHADOGONYAULAX Sarjeant 1966 emend.

Type species: *Dichadogonyaulax culmula* (Norris 1965) Loeblich and Loeblich 1968.

Emended Description: Proximochorate dinoflagellate cysts constructed of an autophragm only. Subspherical in shape, lacking an apical horn. Paratabulation formula: 1pr, 4′, 0a, 6″, x-6c, 6‴, 1p, 1⁗, x-6s, indicated by parasutural crests, ridges, or rows of processes, crests generally ornamented with spines. Accessory ridges absent. Paraplates of the anterior intercalary series absent. Preapical paraplate reduced in size and displaced posteroventrally, resulting in contact between paraplates 2′ and 4′. Combination (epicystal, type E) archeophyle separating from the hypocyst along the posterior margin of the precingular paraplates. Parasutural features on the paracingulum may or may not be reduced on the anterior margin as compared with the posterior margin.

Comparison: The transfer of *D. culmula* to *Alvellodinium* Duxbury by Davey (1982) is herein rejected. *A. falsificum* and *D. culmula* resemble each other in having an epicystal (type E) archeopyle and processes similar to those of *Spiniferites* Mantell. However, Duxbury (1977) reports that *Alvellodinium* has three apical paraplates, and makes no reference to the presence of a preapical paraplate or its position, thus allowing differentiation of the two genera.

Dichadogonyaulax is separated from *Ctenidodinium* by possessing a type of epicystal paratabulation that lacks anterior intercalary paraplates and allows the 2′ and 4′ to be in contact. *Dichadogonyaulax* differs from *Korystocysta* in its epicystal paratabulation and in lacking accessory ridges and apical horn; from *Energlynia* in lacking an antapical horn and possessing an epicyst and hypocyst of nearly equal size.

Accepted species:

D. culmula - (Norris 1965) Sarjeant 1966
D. pannea - (Norris 1965) Sarjeant 1966
D. irregulare - n. sp. herein

Reattributed species:

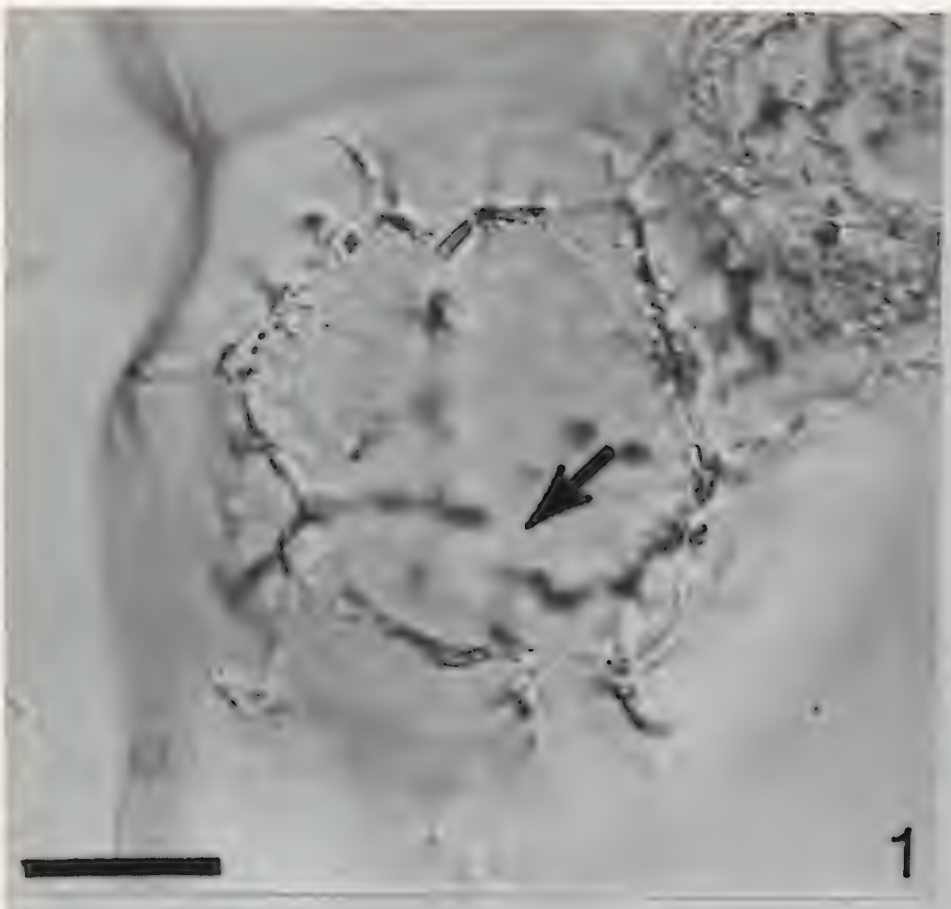
D. rotunda - (Dodekova 1975) Woollam 1983 to *Ctenidodinium* (?)
D. schizoblata - (Norris 1965) Sarjeant 1966 to *Ctenidodinium* (?). This form may represent an intermediate type between *Ctenidodinium* and *Dichadogonyaulax*. The illustration by Norris (1965, fig. 4) of specimen 416/2 shows an anterior intercalary and an apparent preapical area that is displaced posteroventrally allowing 2′ and 4′ to contact. Additional specimens are necessary to determine the consistency of this relationship in this species.
D. sellwoodii - Sarjeant 1975 to *Ctenidodinium*
D. stauromatos - Sarjeant 1975 to *Ctenidodinium* (?)

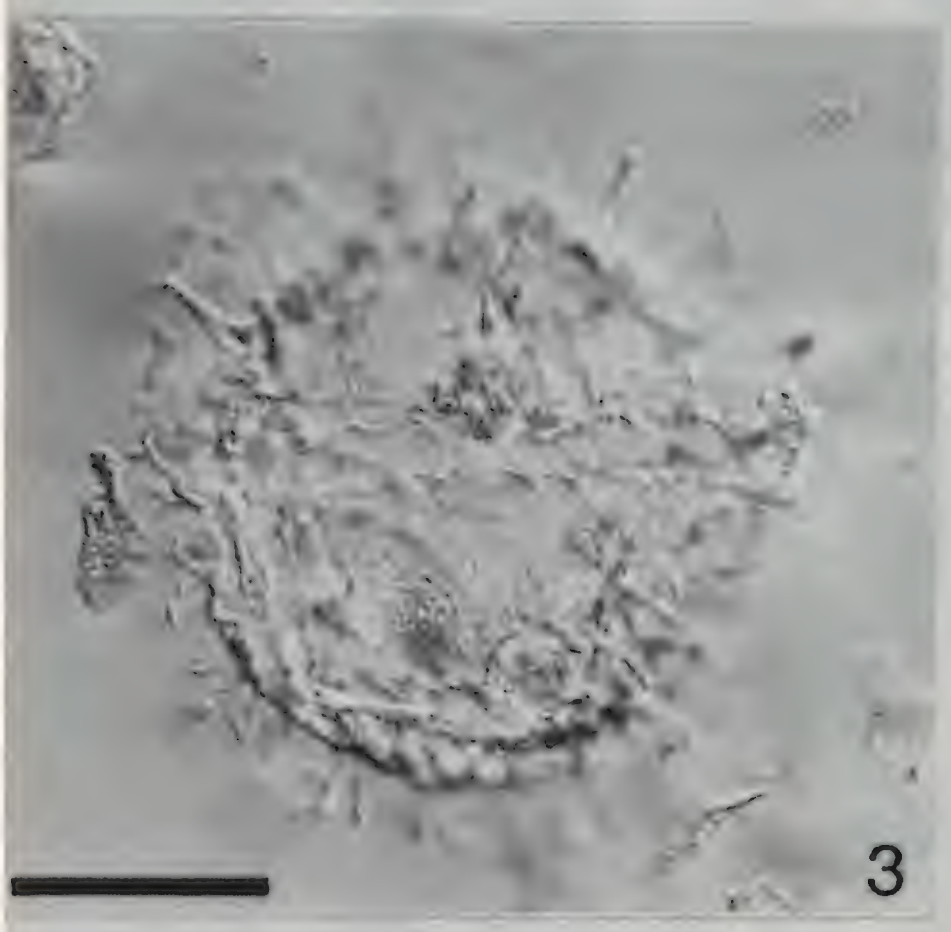
PLATE 3

Figures

1, 2. *Dichadogonyaulax culmula,* Detached epicyst (interior view). The arrow indicates the apparent position of the preapical paraplate. Bar equals 20 μm. P61059A09; R14.9/+0.8, Tithonian, Cherty Series, Portland Beds, Worbarrow Bay, Dorset, England.

3-6. Intact specimen, Figs. 3-5, L. lateral, optical section and R. lateral (interior) views respectively. Note well-developed paratabulation and relatively long processes. Fig. 6, process detail. Bar equals 20 μm. P61060A09 R11.2/+18.7, Tithonian, Cherty Series, Portland Beds, Worbarrow Bay, Dorset, England.





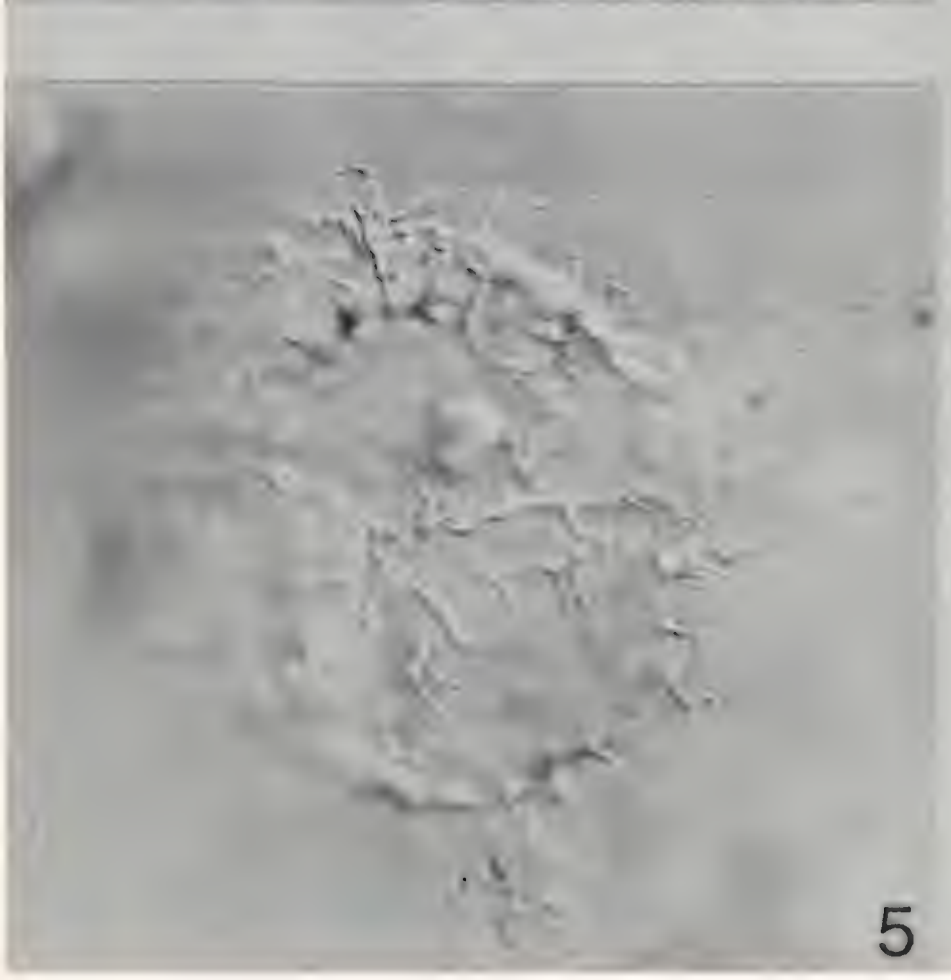


PLATE 3

DICHADOGONYAULAX IRREGULARE n. sp.
Plate 2, figs. 5-12

Holotype: Sample P320C66A; R15.7/+9.7, Pl. 2, figs. 5, 6.

Type locality: Hosston Formation, Amoco No. 1, Crown- Zellerbach; Section 10, T13N, R1W, Winn Parish, Louisiana.

Description: Gonyaulacoid dinocyst with epicystal (type E) archeopyle, operculum generally free. Paratabulation formula: 1pr, 4′, 0a, 6″, xc, 1p, 6‴, 1⁗, xs, expressed by discontinuous parasutural crests which are ornamented with acuminate spines of varying lengths. Paraplates 2′ and 4′ in contact, preapical paraplate displaced posteroventrally. Antapical paraplate only slightly asymmetric and very large (Pl. 2, figs. 11, 12). Cyst surface chagrenate to microreticulate.

Dimensions: Holotype: 49 μm in diameter. Range: 43 (48.5) 51 μm in diameter (20 specimens).

Comments: Most specimens are encountered as isolated epicysts or hypocysts. The discontinuous nature of the parasutural crests is distinctive and exhibits no repetitive pattern that could be distinguished in several hundred observations.

Comparison with similar species: D. irregulare is most similar to *D. pannea* but differs by being slightly smaller, having parasutural crests that are discontinuous in distribution, and by having higher crest ornamentation on the epicyst. *D. irregulare* differs from *D. culmula* in having accuminate terminations on the crest spines rather than bifid terminations as in *D. culmula*. In addition, the parasutural crests of *D. irregulare* do not exhibit the basal perforations that are present in *D. culmula*. The antapical paraplate is larger than in other species of *Dichadogonyaulax*, generally being about half the diameter of the hypocyst.

Occurrence: Lower Cretaceous, Neocomian, north Louisiana subsurface, Atlantic coast offshore subsurface, U.S.A.

Genus KORYSTOCYSTA Woollam 1983 emend.

Type species: *Korystocysta kettonensis* (Sarjeant 1976) Woollam 1983

Emended Description: Proximate dinocysts constructed of an autophragm. Subspherical to ellipsoidal in shape generally bearing an abbreviate apical horn. Paratabulation formula: 1-3pr, 4′, 1-2a, x-6c, 6‴, 1p, 1⁗, x-6s, indicated by parasutural ridges, which may or may not be ornamented with short spines or denticles. Accessory ridges ("growth bands") invariably present, expressed as denticulate or non-denticulate ridges. Combination (epicystal, type E) archeopyle separating along the posterior margin of the precingular paraplates. Operculum free or attached at parasulcus.

Comparison: Korystocysta differs from other genera with epicystal archeopyles by having accessory ridges paralleling its parasutural ornamentation (*i.e.*, "growth bands"), and by possessing an apical horn. The accessory parasutural features readily allow separation of this genus from other related forms, although they may be difficult to discern on poorly preserved specimens (Pl. 1, figs. 3, 11, 12).

Comments: Recently, Gocht (1984) demonstrated "growth bands" on specimens otherwise attributable to *C. combazii* and I have observed similar features on the same species (Pl. 2, fig. 4). If this condition is observed on other species of *Ctenidodinium, Korystocysta* may prove to be a superfluous genus. The emendation also restricts the genus to those forms having preapical and anterior intercalary paraplates and allows the operculum be free or attached. It is the author's experience that epicysts are commonly observed separate from hypocysts and that only in areas of poor preservation are the preapical and anterior intercalary paraplates not evident.

Accepted Species:

K. gochtii - (Sarjeant 1966) Woollam 1983. It is possible that this species may be a junior synonym of *K. kettonensis* and a result of an artifact of preservation. I concur with Woollam's (1983) comment on the difficulty of differentiating these species.

K. kettonense - (Sarjeant 1966) Woollam 1983. Type species (see comments above)

K. pachyderma - (Deflandre 1938) Woollam 1983.

Note: *K. norrisii* (Pocock 1972) Woollam 1983 is considered herein to be a junior synonym of *K. pachyderma*.

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December 5, 1985

REVIEW

THE MAMMOTH HUNTERS, a novel by Jean M. Auel. Published by Crown Publishers, Inc., New York, 1985, x + 645 pp., casebound, $19.95

This is the third in the readable series of novels published by the author treating of life in prehistoric times. It is a continuation of the life of Ayla, the young girl from *The Clan of the Cave Bear* and *The Valley of Horses*. It will be welcomed by those who enjoyed the previous volumes.

—H.C.S.

REVIEWS

ECOLOGIC ATLAS OF BENTHIC FORAMINIFERA OF THE GULF OF MEXICO, by C. Wylie Poag. Published by Marine Science International, Woods Hole, Massachusetts, 1981, ix + 175 pp., illus., folded map, casebound, $29.50 (distributed by Academic Press)

In Part I of this book, Dr. Poag presents the Ecology and Distribution of Predominant Genera [of Foraminiferida throughout the Gulf of Mexico]. Only the abundant and ecologically diagnostic species from the predominant genera are included. The comprehensive treatment of all species present would lengthen the work by hundreds of pages but would add little to its utility and importance to research paleontologists and stratigraphers.

The physiography and geomorphic provinces of the Gulf of Mexico area are described concisely, the climate and the major ecological parameters are discussed, and the history of investigation of the ecology of this important area is reviewed. The generic predominance in eleven bays, lagoons, and estuarine areas is presented in a series of individual maps; ten of these are based on the analysis and re-interpretation of previous studies by other workers. The varied and complex distribution patterns of generic predominance on the continental shelf is treated in detail and is accompanied by a folded map (in pocket) illustrating the distribution of the predominant genera throughout the Gulf of Mexico. The author concludes this section with a discussion of fossil foraminifera and paleoecological interpretation, illustrating the application of ecological data from the Holocene to interpretation of ancient sediments.

In Part II, Description and Illustration of Diagnostic Species, Dr. Poag provides brief taxonomic notes and a summary of the distribution for 138 species of ecologically diagnostic species from the predominant genera in the Gulf region. The text is followed by 64 magnificent plates illustrating these species with scanning electron photomicrographs, a list of references, and an index.

This volume is exceedingly well done and beautifully illustrated. It should have a place on the shelf of every working geologist and paleontologist concerned with Gulf Coast geology and stratigraphy.

DICTIONARY OF THE HISTORY OF SCIENCE, by William F. Bynum, E. Janet Browne, and Roy Porter. Published by the Princeton University Press, Princeton, New Jersey, 1981 (reprinted 1984), xxxiv + 494 pp., paperbound, $12.95

This useful dictionary has been reprinted. It contains seven hundred articles on the ideas and topics and the philosophical and metaphysical principles underlying the leading fields of science, many with bibliographic notes and references. Further, it includes extensive cross-references and an analytical table of contents, and is interspersed with numerous short definitions.

The volume is extremely useful for students of science who need a reference to the key doctrines of science, many of which are difficult to find defined or adequately treated in most science textbooks. The book is paper bound and inexpensive, but it has sewn signatures and will withstand considerable usage. It is highly recommended.

SEDIMENTARY AND EVOLUTIONARY CYCLES, edited by Ulf Bayer and Adolf Seilacher. Published by Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1985, vi + 465 pp., illus., paperbound, $29.50

This is the first volume in a new series, Lecture Notes in Earth Sciences, published by Springer-Verlag and edited by Gerald M. Friedman. This work is the synthesis of a symposium held at Tübingen September 15-17, 1983. It presents twenty-two papers by thirty authors arranged in six sections: Sea-level Changes: General Consequences; Sedimentary Trends in Marginal Epicontinental Basins; Evolutionary and Ecological Replacements in Marginal Epicontinental Seas; Gastropod Evolution in Lakes; The Lower Hierarchy of Cycles: Spatial and Temporal Suibstrate Gradients; and, Ecological and Morphological Gradients. It is a worthwhile volume.

—H.C.S.

AMMOPEMPHIX LACUSTRIS N.SP. (FORAMINIFERIDA) FROM LAC DES ALLEMANDS, LOUISIANA

D. HAMAN and R. E. MAROLT
CHEVRON OIL FIELD RESEARCH COMPANY
LA HABRA, CALIFORNIA

ABSTRACT

Ammopemphix lacustris, n.sp., is recorded from Lac des Allemands, a fresh to brackish water lake located on the upper deltaic plain of the Mississippi Delta. The new species is compared to, and differentiated from, other species assigned to this genus. The relationship of this genus to a homeomorphic Paleozoic genus is discussed.

The occurrence of the genus *Ammopemphix* Loeblich, 1952, has been documented from cold waters in both the northern and southern hemispheres (Loeblich and Tappan, 1964). In the southern hemisphere Wiesner (1931) recorded *A. quadrupla* (as *Urnula quadrupla)* from 66°00′S, 89°31′W in the Weddell Sea at a water depth of 385 meters, and Earland (1934, p. 67) documented the same species as "a few specimens on a stone from 152 meters at St. WS 482," Antarctica. In the northern hemisphere Cushman (1933) noted *A. arctica* from a water depth of seven fathoms off northeast Greenland. Consequently, to date, published records indicate that the genus may be regarded as a cold water marine form, which lives at water depths in excess of 12 meters.

The purpose of this article is to document the presence of the genus in a fresh to brackish water lacustrine subenvironment in Louisiana, indicating that the genus has a more cosmopolitan distribution than previously believed. This ecologic differential, plus the difference in test wall composition of this species compared to other described *Ammopemphix* species, justifies the establishment of a new species.

SYSTEMATIC DESCRIPTION

Order
FORAMINIFERIDA Eichwald, 1830
Suborder TEXTULARINA
Delage and Herouard, 1896
Superfamily
ASTRORHIZACEA Brady, 1881
Family HEMISPHAERAMMINIDAE
Loeblich and Tappan, 1961
Subfamily HEMISPHAERAMMININAE
Loeblich and Tappan, 1961
Genus *AMMOPEMPHIX* Loeblich, 1952

AMMOPEMPHIX LACUSTRIS sp. nov.
Text figs. 1-3

Description: Test free, formerly attached, multilocular, sub-ovate in outline with lobulate periphery, plano-convex in side view; composed of four agglomerated equisized, subglobular, closely adpressed chambers, arranged in a symmetrical pattern; dorsal side convex, vertical side flat to very slightly concave, junction between dorsal and ventral sides angular, dorsal sutures depressed, distinct, ventral sutures indistinct, flush; aperture a single circular to irregular opening, at dorsal summit of each chamber, raised slightly above chamber surface: test wall rough, predominantly composed of randomly arranged siliceous spicules with minor fine-grained arenaceous material; ventral surface with thin, easily ruptured, translucent membrane.

Test dimensions: Maximum diameter 580 μm; Height 200 m.

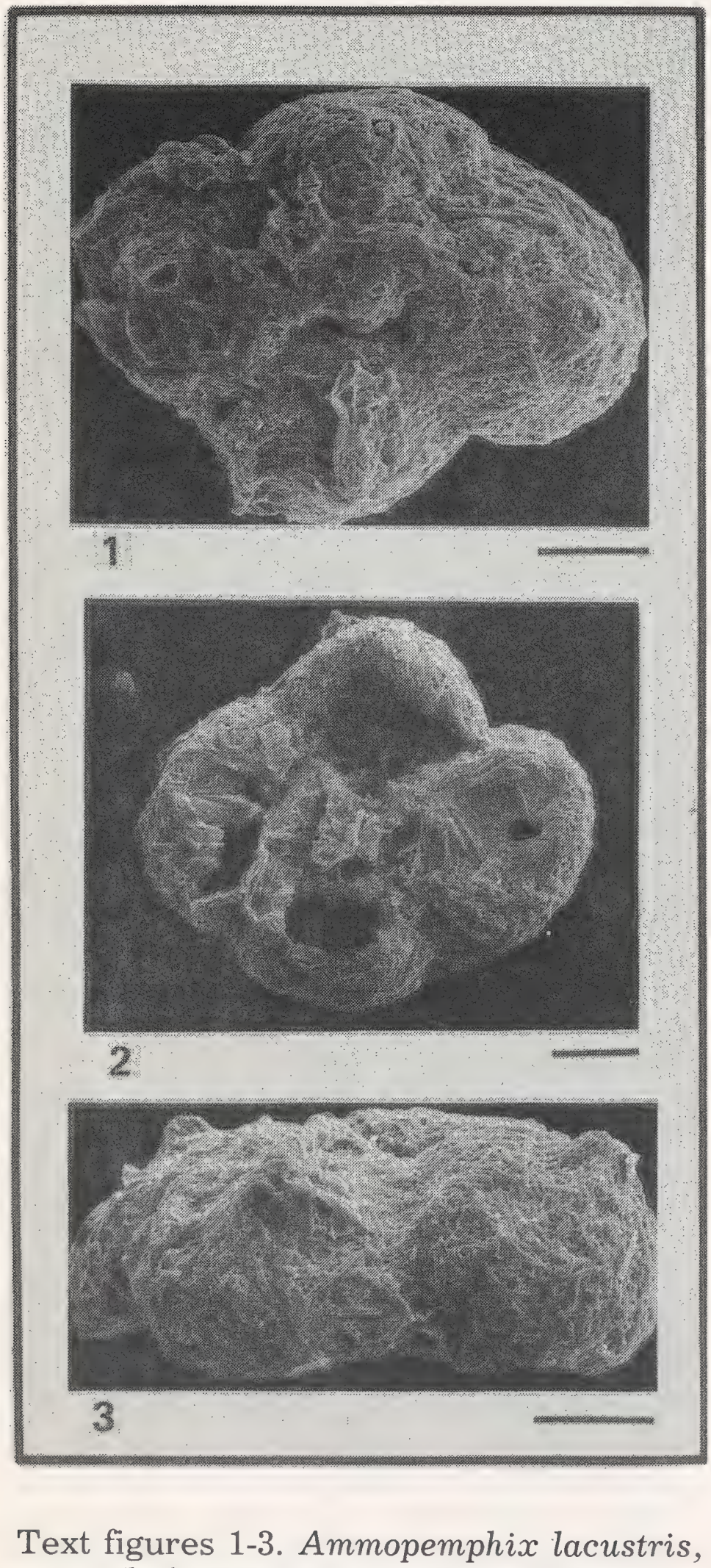
Type Locality: Lac des Allemands, Louisiana, approximately two miles south of Pointe aux Herbes and 3.5 miles due west of Baie des Deux Chenes.

Locality environmental parameters: Water depth 2.13 meters, surface water temperature 29.0°C, salinity 0.01‰; sediment - water interface temperature 27.0°C; salinity 1.34‰.

Stratigraphic level: Modern.

Associated microfauna: Centropyxis constricta (Ehrenberg), *C. ecornis* (Ehrenberg), *Difflugia capreolata* Penard, *D. mitriformis* Wallich, *D. oblonga* Ehrenberg, *D. pyriformis* Perty, *D. urceolata* Carter, *Lesquereusia modesta* Rhumbler, *Pontigulasia compressa* (Carter), *Ammotium morenoi* (Acosta), *Ammobaculites* spp.

Comparison: This species exhibits similarity in overall shape to *A. arctica* (Cushman, 1933, pl. 1, figs. 2a, 2b, *non* figs. 1a-1c) and *A. quadrupla* (Wiesner 1931, pl. 6, figs. 56-57). Conversely the material composing the test wall of these two species differs significantly from that of *A. lacustris* n.sp. The test wall of both *A. quadrupla* and *A. artica* is predominantly composed of fine-grained arenaceous material (fide Loeblich and Tappan, 1964) whereas in *A. lacustris* it is pre-



Text figures 1-3. *Ammopemphix lacustris*, n.sp., (holotype) (1) dorsal view, (2) ventral view, (3) side view; scale bar = 100 μm.

dominantly composed of siliceous spicules with only minor fine-grained arenaceous material.

Discussion: Loeblich and Tappan (1964, p. C202) categorize the genus *Ammopemphix* as having a test in which the chambers are "usually symmetrically arranged with few chambers in a single whorl, or with outer ring of chambers." The use of the term "whorl," which the same authors define *(ibid.*, p. C65) as "a single turn or volution of coiled test" suggests an organized growth mode. Haynes (1981, p. 102) refers to *Ammopemphix* as a "pseudocolony" and consequently regards this genus as a synonym of the unilocular genus *Colonammina* Moreman, 1930. We have retrieved in excess of 40 *Ammopemphix* specimens from Lac des Allemands. These specimens exhibit a variation in chamber number from one to four, with a few specimens having in excess of ten chambers. A manuscript in preparation documents the variability exhibited by this taxon. Based on our specimens we agree with the observation of Haynes (1981) and conclude that *Ammopemphix* does in fact represent a random agglomeration of single chambers. Any test symmetry or appearance of growth habit we believe to be purely fortuitous.

At present, however, we are hesitant to refer our specimens to the genus *Colonammina* Moreman because this genus has only been recorded from Paleozoic strata (Conkin and Conkin, 1982). Loeblich and Tappan (1964) and Haynes (1981) extend the range of *Colonammina* Moreman to the Recent. Apparently the reason for this range extension is their subjective inclusion of the Modern genus *Psammoscene* Rhumbler *in* Wiesner, 1931 (*Psammoscene* Thalmann, 1934) in the synonomy of *Colonammina* Moreman (*fide* Loeblich and Tappan, 1964). We are of the opinion that *Psammoscene* Thalmann, originally retrieved from Recent sediments obtained during the German Southpolar Expedition (1901-1903) is more appropriately included in the synonomy of *Ammopemphix*. We also believe that this synonomy has greater validity due to the fact that we have retrieved single chambered *Ammopemphix* forms from our Recent sediments. We see little merit in uniting a Recent genus with one from the Paleozoic, especially when occurrences of the taxon from intervening intervals have not been documented. Our approach therefore restricts *Colonammina* Moreman to the Paleozoic and unites the Recent forms under the name *Ammopemphix* Loeblich, 1952.

ACKNOWLEDGMENTS

The authors are indebted to Messrs. C.J. Ford and G.L. Armstrong for technical support, to E.E. Schwartz for secretarial support, to Dr. W.S. Drugg for offering constructive criticism, and to Chevron Oil Field Research Company for publication permission.

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ON A REDUNDANT GENERIC ASSIGNMENT OF *TEXTULARIA FLORIDANA* CUSHMAN, 1922

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Textularia floridana was first described from shallow waters off Florida (Cushman, 1922). Since that time the species has been documented from widespread areas of the world (Halicz and Reiss, 1979). Cushman's assignment of this species to the genus *Textularia* Defrance *in* de Blainville, 1824, has not been accepted by a number of students. For example, Phleger and Parker (1951) assigned their Gulf of Mexico individuals to the genus *Spiroplectammina* Cushman, 1927, and Hofker (1969) placed his Barbados specimens in the genus *Septigerina* Keijzer, 1941. This latter designation immediately extended the range of the Eocene genus *Septigerina* Keijzer, to the Modern.

Halicz and Reiss (1979) documented Red Sea Textulariidae and in this work reviewed the species *Textularia floridana* Cushman. Based on their review, they (*ibid.*) selected this species as the type for their new genus *Neoseptigerina*. The new genus was distinguished from *Septigerina* Keijzer by the character of the interseptal secondary speta (Halicz and Reiss, 1979).

Textularia floridana Cushman was also selected by Mikhalevich (1981) as type for the new genus *Fissotextularia*. The establishment of the genus *Fissotextularia* Mikhalevich is redundant as it is a junior objective synonym of *Neoseptigerina* Halicz and Reiss (1979) (ICZN. Art. 61b). Consequently, the species *Textularia floridana* Cushman should be retained in the senior synonymic genus (ICZN Art. 67e).

I thank Dr. W.S. Drugg for technical assistance and Chevron Oil Field Research Company for publication permission.

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LIPPSINA, A NEW NAME FOR *NONIONOIDES* SCHÄFER, 1980, *NON* SAIDOVA, 1975 (FORAMINIFERIDA)

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Saidova (1975) introduced the generic name *Nonionoides* for foraminiferid specimens obtained from Modern Pacific Ocean samples. She (*ibid.*, p. 248) selected *Nonionina grateloupi* d'Orbigny (1826) as the type species for this genus.

In 1980, Schäfer also used the generic name *Nonionoides* for Aquitanian specimens from the Mainz Basin, Germany. The species *Nonion demens* Bik (1964) was selected as type (Schäfer, 1980, p. 194).

A new name is required for *Nonionoides* Schäfer, 1980, a junior homonym of *Nonionoides* Saidova, 1975 (ICZN, Art. 53b). Attempts to contact the author of the junior homonym in order to correct this oversight have been unsuccessful. Consequently, as some five years have passed without this error being rectified, the name *Lippsina* is herein proposed as replacement for *Nonionoides* Schäfer, 1980.

The new name is constructed in honor of Dr. Jere H. Lipps in recognition of his contributions as a foraminiferologist.

ACKNOWLEDGMENT

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December 5,1985

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION – XXVII: ON THE OCCURRENCE OF THE BIVALVE GENUS *NUCINELLA* WOOD

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Recently, sorting some fine-sieving from Tulane University locality TU 999 in the Chipola Formation (Farley Creek, a tributary of the Chipola River), the writer found a single left valve of a new species of the genus *Nucinella* Wood, 1851. Careful examination of material previously sorted from all of the 57 Tulane localities in the type area of the formation failed to reveal any additional valves. This scarcity is not unusual, however; of the 35 described species of the genus known to the writer, 11 were based upon single valves.

Family MANZANELLIDAE Chronic, 1952
Genus NUCINELLA Wood, 1851

Pleurodon WOOD, 1840, Mag. Nat. Hist., (N.S.) v. 4, p. 230 [*non* Harland, 1831, Jour. Acad. Nat. Sci. Phila., v. 6, p. 284 (Mammalia)].
Type species (by monotypy): *Pleurodon ovalis* Wood, 1840.

Nuculina D'ORBIGNY, 1844, Paleont. France, Cret. Lamell., p. 161 [*non* "Filippi" Poro, 1837, Bibl. Ital., v. 82, p. 65 (Crustacea ?)]
Type species (by montypy): *Nucula miliaris* Deshayes, 1829; Eocene, Paris Basin, France.

Nucinella WOOD, "1850" [1851], Mon. Crag. Moll. (Paleontogr. Soc. Mon.), pt. 2, Bivalves, p. 72.
Type species: "*Nucula miliaris*, Deshayes" (*not* of Deshayes, 1829) = *Pleurodon ovalis* Wood, 1840; Pliocene, Coralline Crag, England (see discussion below).

Cyrillona IREDALE, 1929, Rec. Aust. Mus., v. 17, p. 160.
Type species (by orig. designation): *Cyrilla dalli* Hedley; Recent, New South Wales, Australia.

Neopleurodon HERTLEIN and STRONG, 1940, Zoologica, v. 25, p. 419.
Type species (by orig. designation): *Pleurodon subdolus* Strong and Hertlein, 1937; Recent, Gulf of California.

Wood (1851, p. 72), in his discussion of the genus *Nucinella* and the sole species that he referred to it – "*Nucinella miliaris* Deshayes" (with *Pleurodon ovalis* listed as a synonym), noted that "there is reason to believe the species left in the Paris Basin is the true progenitor of our little shell. . . . As, however, some differences exist between the Crag Fossil, and what is here considered its specific parent, it may be necessary to give a more detailed description and to point out what, perhaps, might be regarded by some Conchologists as of sufficient importance to keep them distinct.

". . . In a specimen of the French Eocene Fossil in my own cabinet, the teeth do not appear to be quite so obtuse as in the Crag shell, and the umbo is somewhat sharper and more terminal, with a rather more angular outline, the posterior side is apparently more truncated or straight, while the shell is nearly transparent."

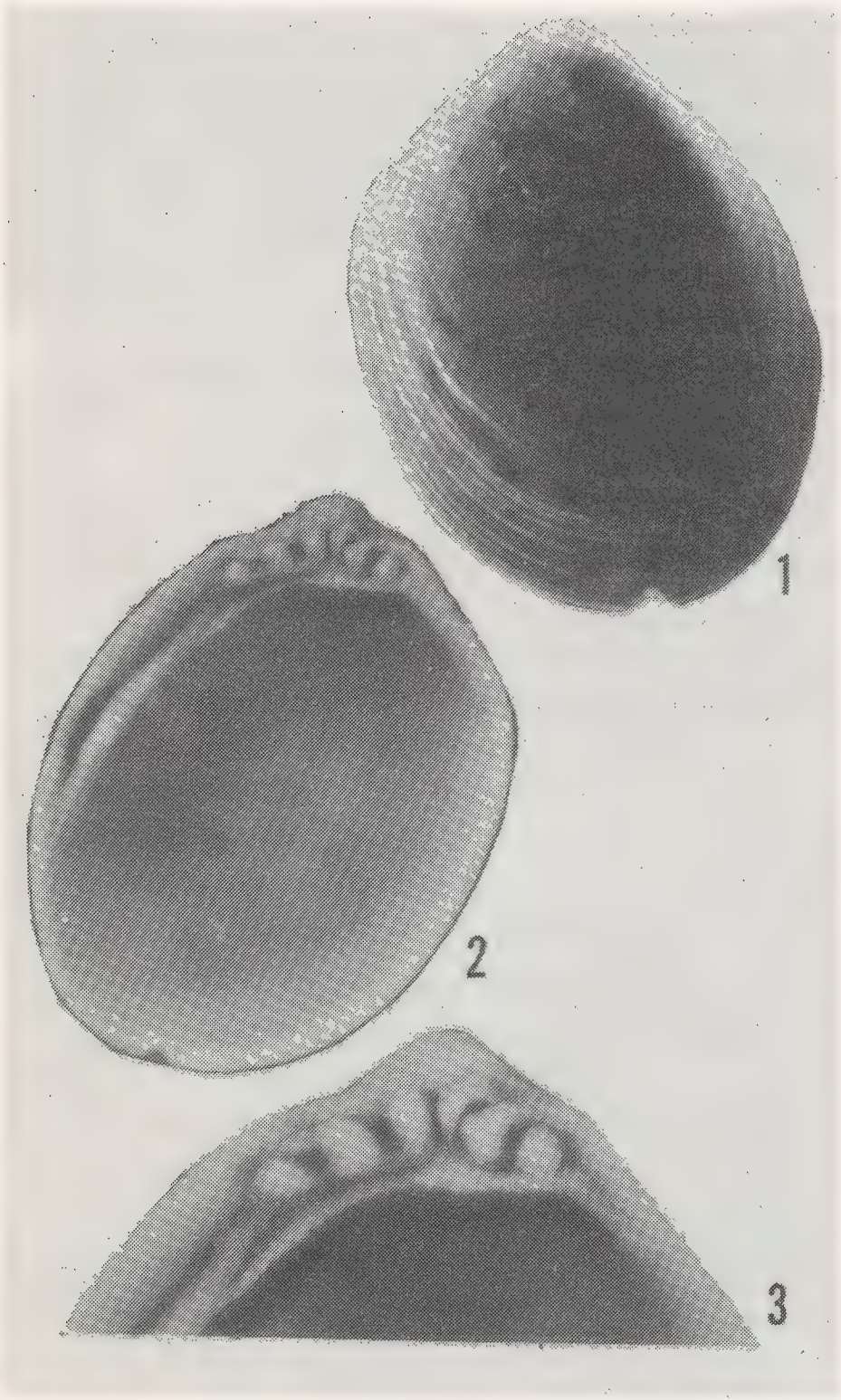
It should be noted that, as far as the writer has been able to discover, no subsequent authors have agreed with Wood's conclusions as to the specific identity of the Eocene and Pliocene forms, and generally have considered that there are two species included in the original description of the genus. In 1871, Stoliczka (p. xxi) designated *Pleurodon ovalis* as the type species. [For a more detailed discussion of the problem of the type species see Vokes, 1956, p. 653-655.]

NUCINELLA CHIPOLANA
H. E. Vokes, n. sp.
Text figure 1

Description: Shell of average size for the genus; tumid, with greatest inflation at anterior third of valve height; umbo small, slightly prosogyrate, with a minute glassy protoconch; dorsal third of anterior margin of valve straight, with a strong antero-ventral slope that rounds rather sharply into a broadly convex ventral segment trending posteriorly at an angle almost equal to the anterior trend of the dorsal portion; ventral margin broadly and regularly rounded, passing gradually into the gently convex posterior side; dorsal margin relatively short and gently arched above and slightly sub-auriculate at anterior end, rounded at posterior one.

Exterior of valve smooth, marked by fine incremental lines developing ventrally into weak, inconspicuous undulations.

Hinge typical of genus, consisting of a sub-umbonal series of taxodont "cardinal" teeth located on a hinge plate, relatively flat transversally on the anterior area up to and immediately below the umbo, but then gradually trending down into the valve as it passes along the dorsal half of the inner posterior margin, bearing on its ventral half an erect triangular laminar lateral tooth;



Text figure 1. *Nucinella chipolana* Vokes, n. sp. USNM 398344; height 2.75 mm, length 2.1 mm; figs. 1, 2, × 16; fig. 3, × 28 (magnifications approximate).

"cardinal" teeth divided into anterior and posterior segments by a narrowly subtrigonal tooth projecting from valve margin immediately below the umbo; this tooth, broader at its dorsal extremity and narrowing ventrally to a thin lamina that terminates slightly above the ventral ends of the adjacent, more broad, anterior and posterior teeth; dorsal ends of two lateral sets of "cardinal" teeth trending ventrally, as the slightly raised hinge margin parallels the arched valve margin; this results in the dorsal sides of the intermediate tooth sockets being raised and appearing as if projecting from the lateral margin of the adjacent, more centrally located, tooth giving these teeth a distinctly chevron-shaped appearance; two "cardinals" lying in front of the median subtrigonal tooth and three behind it, the most posterior one lacking the chevron shape and essentially only a transversely elongated node.

Inner margin smooth; pallial line entire; posterior adductor scar relatively large, slightly impressed and situated immediately below the lateral tooth; anterior adductor not well delineated.

Holotype: USNM 398344; height 2.75 mm, length 2.1 mm, diameter (left valve) *ca.* 0.8 mm.

Type locality: TU 999; Farley Creek, south bank *ca.* 900 feet west of bridge on Florida Highway 275 (SW ¼ Sec. 21, T1N, R9W).

Discussion: Nucinella chipolana is the fourth species of this genus to be reported from the Tertiary faunas of the eastern Atlantic region. *Nucinella alleni* Vokes (1966, p. 38, text fig. 1), from the Cook Mountain Formation (Claibornian, Middle Eocene) of Louisiana, is a much smaller form, with but two "cardinal" teeth; *N. gunteri* (Mansfield) (1932, p. 37, pl. 2, figs. 4, 6, as *Pleurodon),* from the Late Miocene "*Arca* zone of the Choctawhatchee Formation" (= Red Bay Formation of Choctawhatchee Group) of Florida, is approximately the same size as *N. chipolana* but has a distinctly broader medial "cardinal" tooth, with but one anterior and two posterior teeth; in addition, the valve seems proportionately narrower with a longer straight, dorsally-sloping segment on its anterior valve margin; *N. woodii* (Dall) (1898, p. 600, pl. 24, fig. 10, as *Pleurodon),* from the Caloosahatchee Formation, Late Pliocene of Florida, is marked by the possession of three relatively narrow anterior "cardinals" that traverse the hinge plate in a diagonal row from a point near the anterioventral margin of the plate to its dorsal side immediately in front of the umbo. Mansfield (1932, p. 37, pl. 2, figs. 1,3) reported a right valve that he identified with Dall's Caloosahatchee form from the "*Cancellaria* zone" (= Jackson Bluff Formation) from Jackson Bluff, Florida. Comparison of his illustrations with that of Dall seems, as earlier noted by the present writer (1956, p. 663), to indicate that the Jackson Bluff form is proportionately shorter than the Caloosahatchee one, that the posterior lateral is slightly more distant from the "cardinals" and that the arrangement of the latter teeth is completely different, particularly with respect to the anterior series. On the whole, the Mansfield form seems

more closely related to the present Chipola species, especially the arrangement of the "cardinals" with the anterior and posterior series being separated by a narrowly subtrigonal median tooth, which is situated higher on the hinge-plate than any of those on either side.

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NOTES ON THE FAUNA OF THE CHIPOLA FORMATION – XXVIII: ON THE OCCURRENCE OF THE NON-MARINE GENUS *MYTILOPSIS* (MOLLUSCA : BIVALVIA)

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Material collected from the Chipola Formation, Early Miocene, at Tulane locality 459 on the east bank of the Chipola River, Calhoun County, Florida, has yielded seven valves of *Mytilopsis*, a genus primarily known from the lower reaches and mouths of rivers within the tropical zone of the Western Hemisphere. Associated with these valves in the collection are more than 100 specimens of a small species of the fresh-water gastropod *Planorbis*, plus many valves of what appears to be a new species of the estuarine genus *Mulinia*, abundant donacids, and other forms indicative of a shallow-water environment adjacent to the mouth of a small fresh-water stream. This is the only locality in our Chipola collections with a fauna suggesting such a depositional environment.

Family DREISSENIDAE Gray *in* Turton, 1840 [ICZN Direction 41, 1956]

Genus MYTILOPSIS Conrad, 1858

Mytilopsis CONRAD, 1858, Acad. Nat. Sci. Phila., Proc., v. 9, p. 167.

Praxis ADAMS and ADAMS, 1857, Genera Recent Mollusca, v. 2, p. 522 (*non* Guenée, 1852, Lepid.).

Mytiloides CONRAD, 1874, Acad. Nat. Sci. Phila., Proc., v. 26, p. 29 [err. pro *Mytilopsis*, *fide* Conrad, *supra* p. 83] (*non* Brongniart, 1822, Inoceramidae).

Type species, by subsequent designation, Dall, 1898 : *Mytilus leucopheatus* Conrad, 1831; Recent, southeastern United States.

"Shell mytiliform, attached by a byssus; hinge with a septum, beneath which on the cardinal side is a triangular cup-shaped process; cartilage groove rather deep." (Conrad, 1858)

The "triangular cup-shaped process" beneath the septum – a myophore – distinguishes *Mytilopsis* from *Dreissena* van Beneden, 1835 [emend. pro *Driessena*, Intl. Comm. Zool. Nomen., Opinion 351, 1955].

MYTILOPSIS ERIMIOCENICUS
H.E. Vokes, n. sp.
Text figures 1-3

Description: Shell small, mytiliform, inflated, with a rather strong, rounded antero-postero crest sloping gently to the broadly arched dorsal/postero-dorsal margin, but steeply to the ventral one; the latter straight to slightly concave, sharply rounded into posterior margin; umbones anteriorly terminal, subangulately rounded, smooth; valve surface marked only by growth lines, a hint of fine radial striae on worn specimens; interior septum characteristic of genus, more deeply inset on right valves than on left, myophore on dorsal side below septum, small; anterior half of dorsal margin of left valve grooved for reception of low, narrow and inconspicuous ridge on margin of right valve; posterior adductor scar slightly bilobed.

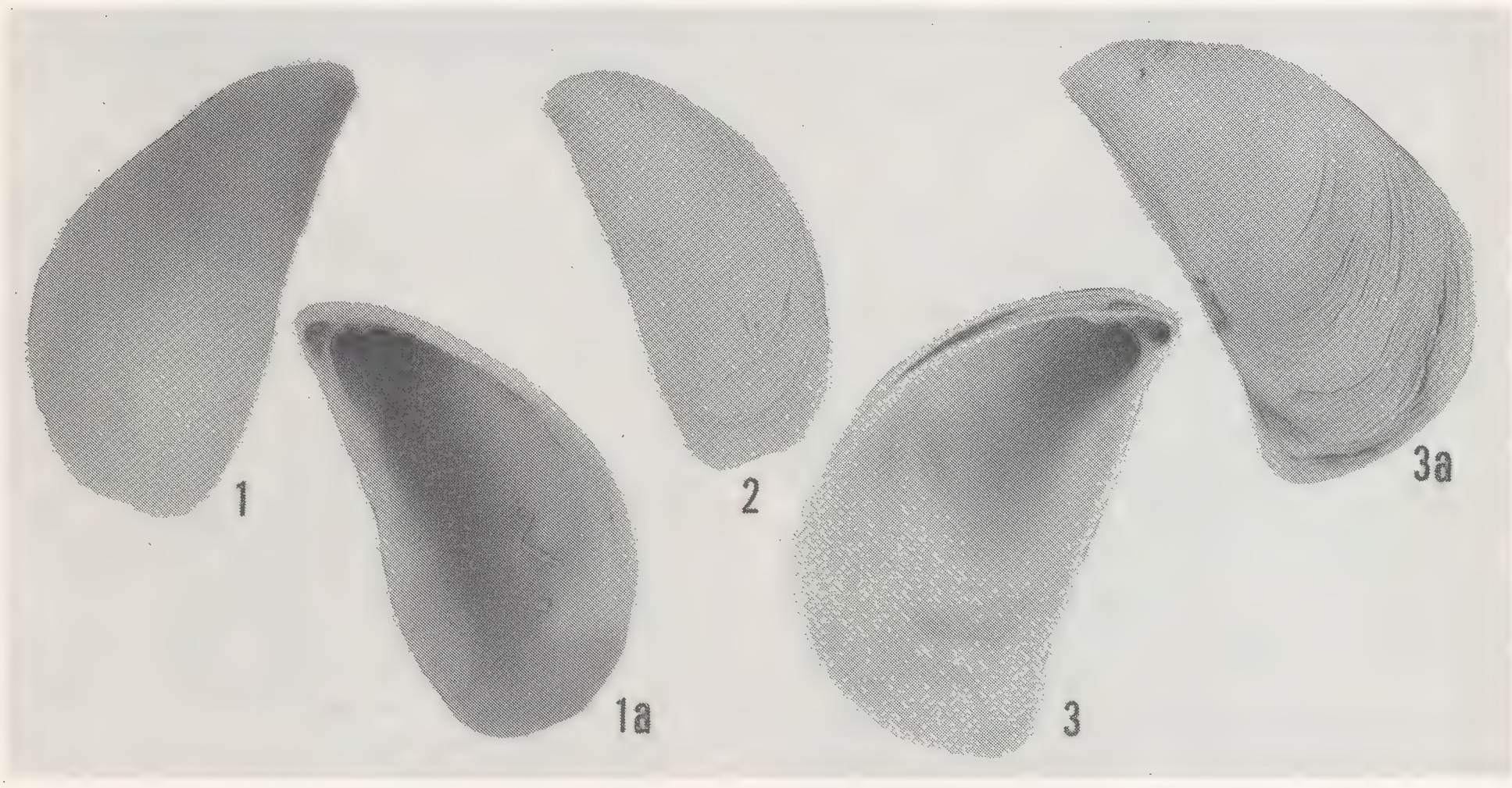
Holotype: USNM 398345; length 7.3 mm, height 4.2 mm, semidiameter (left valve with slightly damaged postero-ventral margin *ca.* 1.5 mm.

Paratype: USNM 398346; length 7.1 mm, height 3.3 mm, semidiameter (right valve) 1.2 mm.

Paratype: USNM 398347; length 6.2 mm, height 3.0 mm, semidiameter (left valve) 1.0 mm.

Type locality: TU 459; Chipola Formation, east bank of Chipola River; steep bank about 1500 feet above the mouth of Taylor Lake Branch (NW ¼ Sec. 29, T1N, R9W), Calhoun Co., Florida.

Remarks: Mytilopsis erimiocenicus n. sp. is, in-so-far as the writer is aware, the first species of the genus to be reported from the Miocene strata of the Atlantic and Gulf Coastal area. *Mytilopsis cira* Pilsbry and Olsson (1935, p. 19, pl. 5, fig. 2), from the Late Oligocene or Early Miocene of the Magdalena Embayment area of Colombia, the only species of possible equivalent or slightly older age that has been described from the western Atlantic faunas, differs greatly in shape with a sharply angulate umbonal ridge, a straight dorsal margin and a flattened to slightly convex ventral margin, forming a much more broadly expanded valve than that of the present species, as indicated by the measurements cited (length 16.75 mm, height 14 mm for



MYTILOPSIS ERIMIOCENICUS Vokes, n. sp.

Figures
1. Paratype, USNM 398345; exterior of right valve; 1a, interior of right valve.
2. Paratype, USNM 398346; exterior of left valve.
3. Holotype, USNM 398347; interior of left valve; 3a, exterior of left valve – largest specimen in collection.

All figures approximately × 6.

one valve; a second one with length 18.25 and height 16.50 mm).

The form figured by Maury (1917, p. 195, pl. 39, fig. 5) from the Early Pliocene Cercado Formation on the Rio Cana at Caimito, Dominican Republic, and identified as "*Mytilopsis domingensis* Recluz," a Recent species (described as *Dreissena domingensis)* from Haiti, differs in the broadly flaring and flattened dorsal edge of the valve. As noted by Weisbord (1964, p. 209) Maury's figured specimen is probably incorrectly identified as the Recluz species, which has recently been synonymized with the type species, *M. leucopheatus* (Conrad) (see Marelli, 1980, p. 12).

Mytilopsis lamellatus (Dall) (1898, p. 809, pl. 35, figs. 13-15) from the Late Pliocene Caloosahatchee Formation of Florida is similar to the present Chipola species, but differs in the broad angulation between the relatively straight anterior portion of the dorsal slope and the point where it begins to curve toward the posterior end. The ventral margin is also slightly more concave in most specimens, although some examples in the Tulane collection have a straight one, and one or two are even slightly convex. The growth lamellae on the surface of the larger specimens is also distinctive, but small forms of a size equivalent to the new species tend to have the lamellae only weakly developed, if at all.

The Bowden species *M. jamaicensis* Woodring (1925, p. 86, pl. 10, figs. 13, 14) has an angulate dorsal margin with the marginal groove on the left valve much shorter than present on *M. erimiocenicus*.

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NOTES ON THE FAUNA OF THE CHIPOLA FORMATION - XXIX
A NEW SPECIES OF *PANOPEA* (MOLLUSCA: BIVALVIA)

HAROLD E. VOKES

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Dall (1898, p. 829) reported the presence of *Panopea* Ménard in the fauna of the "Oligocene...of the Chipola River and Oak Grove...Florida," identifying the species as "*Panopea Whitfieldi,*" a new name for "*Panopea Goldfussii* Whitfield" 1895, *non* Wagner, 1838. He repeated the citation as to the distribution in 1915 (p. 156, pl. 18, fig. 13) spelling the generic name *Panope* (see discussion below). Subsequently Gardner (1928, p. 237, pl. 36, figs. 11, 12) described the Oak Grove form as *Panope parawhitfieldi,* noting: "The Chipola species is apparently distinct from the Oak Grove, differing in the more produced and attenuated posterior extremity. The material is too fragmentary to name."

The Tulane University collections from the Chipola Formation, now known to be Lower Miocene, Burdigalian, in age, contain several thin-shelled specimens (six of which are paired valves) in varying degrees of completeness, which are here referred to the new species *Panopea chipolana.*

Family HIATELLIDAE Gray, 1824
Genus PANOPEA Ménard, 1807

Glycimeris LAMARCK, 1799, Mem. Soc. Hist. Nat. Paris, v. 7, p. 83 (*non Glycymeris* Da Costa, 1778; *Glycimeris* Lamarck, 1801, etc.).

Panope MÉNARD, 1807 (?January), Mémoire sur un nouveau genre de coquille bivalve-équivalve de la famille des Solénoides intermediaire aux Solens et aux Myas..., p. 30.

Panopea MÉNARD, 1807 (April), Ann. Mus. Hist. Nat. Paris, v. 9, p. 135.

Panopaea LAMARCK, 1819, Hist. Nat. Anim. sans Vert., v. 5, p. 456.

Type species: By subsequent designation, Children, 1823, *Panopea aldrovandi* Ménard, 1807 = *Mya glycimeris* Born, 1778. Recent, Mediterranean Sea and Atlantic coasts of Spain and Portugal.

Discussion: There has been considerable uncertainty concerning the generic name to be applied to the molluscan group to which the present and related species are to be assigned. Lamarck, in 1799, proposed the name *Glycimeris* for *Mya glycimeris* Born, but in 1801 applied the name to the taxonomic group presently referred to *Cyrtodaria* Reuss, 1801. Subsequently, it was noted that the name *Glycymeris* (spelled with two "y's") had been proposed as early as 1778 by Da Costa for the species to which that name is now formally applied, in place of *Pectunculus* Lamarck, 1799, which term had also been used by Da Costa in 1778 and now considered as representing a subgenus of *Dosinia* Scopoli, 1777.

The uncertainty resulting from Lamarck's two differing usages of *Glycimeris* early led to the proposal of the name *Panopea* (or *Panope*) by Ménard de la Groye in 1807. According to Dall (1912, p. 34), "M. Ménard states expressly that Lamarck agreed with him as to the necessity for a new name for the genus..." The term *Panopea* was used almost constantly from the date of its appearance in the Annales du Museum of Paris in April of 1807. But Dall in 1912 (p. 34) called attention to a pamphlet, dated as of January, 1807, in which the name was spelled *Panope*, a name based upon the Greek name for a mythologic sea nymph. According to Dall, the copy of the pamphlet in his collection contained annotations, in Ménard's handwriting, concerning the April paper. Subsequent investigations revealed a second copy in the library of the Museum d'Histoire Naturelle in Paris, which also bore Ménard's annotations, plus evidence that another copy had been sold by a French bookseller in 1954; the latter, however, has not been traced. The weight of the evidence points to the conclusion that even though the pamphlet may have been printed in January, it probably was not distributed until somewhat later. Accordingly, in 1960 the writer and L.R. Cox, then Keeper of Invertebrate Paleontology at the British Museum, proposed that the problem be reviewed by the International Commission on Zoological Nomenclature and that the long-used term *Panopea* be placed on the *Official List of Generic Names* (see Vokes and Cox, 1961); the proposal was recently revived by R.V. Melville, Secretary of the Commission (1983) and presumably soon will be voted upon by the Commission members.

PANOPEA CHIPOLANA
H.E. Vokes, n. sp.
Text figures 1-3

Panope sp. indet., GARDNER, 1928, U.S. Geol. Surv., Prof. Paper 142-E, p. 238.

Description: Shell of moderate size for the genus (largest specimen in collection 92.4 mm long, 50.0 mm high), thin, inflated, inequilateral, widest subumbonally at anterior third of length; valves narrower and more broadly gaping posteriorly than anteriorly; low concentric undulations on and adjacent to the broad, flattened umbos that project only slightly above the dorsal margins; undulations dying out away from the umbones, with the surface marked mainly by low inconspicuous incrementals that tend to be somewhat more prominent toward the dorsal margins; some valves showing a very low broadly rounded posterior umbonal ridge extending posteriorly but dying out before reaching the valve margin; dorsal margin straight, anterior margin broadly rounded, passing gradually into a convex ventral one with posterior margin regularly rounded, only slightly more than half the width of the anterior one; lunule and escutcheon absent; ligamental nymphs projecting, relatively short for genus; a single, small, laterally compressed cardinal tooth in each valve; internal margins smooth; adductor scars relatively small, moderately prominent due to a slight thickening of the shell inside the relatively prominent pallial line; a deep posterior pallial sinus extending beyond the mid-length of the valve.

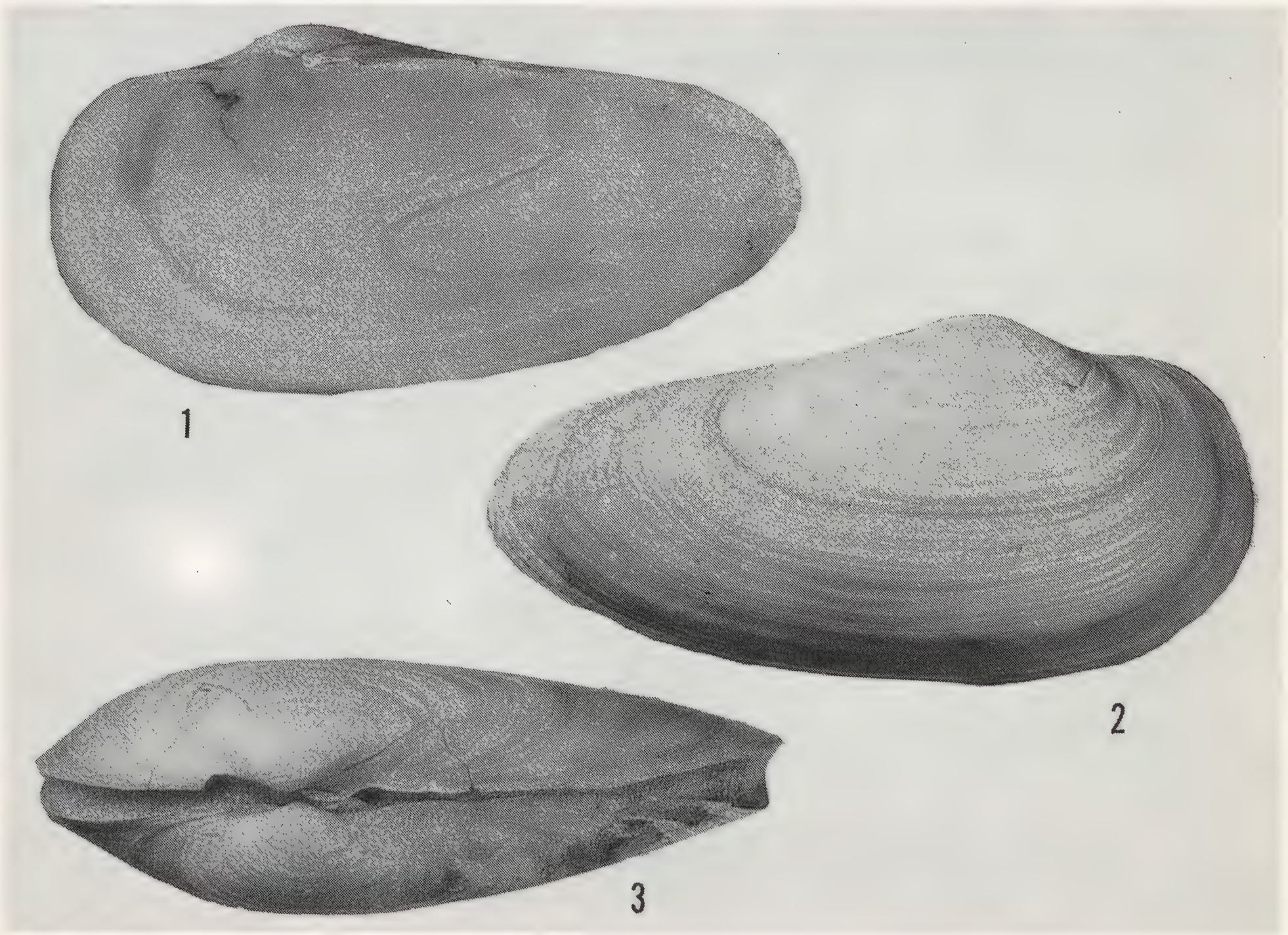
Holotype: USNM 402707; length 78.0 mm, height 38.4 mm, diameter, (paired valves) 16.1 mm.

Type locality: TU 549, east bank of Chipola River, about one-fourth mile below Four Mile Creek (NE 1/4 Sec. 32, T1N, R9W), Calhoun Co., Florida.

Discussion: Although not common, *Panopea chipolana* seems to occur throughout the formation. The holotype specimen is from Tulane locality 549, near the top of the formation as exposed on the Chipola River; other specimens, however, are from localities in the basal beds on Tenmile Creek (TU localities 546, 817, 830) and toward the central part of the formation on Farley Creek, near its mouth where it enters the Chipola River (TU localities 819, 825).

As noted by Gardner (1928, p. 237, 238) the present Chipola species differs from *P. parawhitfieldi* Gardner (1928, p. 237, pl. 36, figs. 11, 12) in its "more produced and attenuated posterior extremity...[with the] umbones more decidedly anterior...and the umbonal sculpture lacks the strength and regularity...of *P. parawhitfieldi,* and the sinus is produced to the vertical dropped from the beaks."

The Upper Eocene (Jackson) and Lower Oligocene (Vicksburg) *"Panopaea" oblongata* Conrad (1848, p. 290 - see Dockery, 1982, p. 101, pl. 52, figs. 1a-c [Conrad's type], 6) seems more closely related to *P. parawhitfieldi* than to the present species. Conrad's type appears to be somewhat incomplete anteriorly, but the smaller form shown in Dockery's figure 6 has slightly more anteriorly located umbos, and more broadly convex ventral margin while maintaining a similarly broad posterior segment of the valve. All three of the above species differ from the later Tertiary and Recent forms in their proportionally more elon-



Text figures 1-3 (X 1). Holotype, USNM 402707. Fig. 1, interior of right valve; fig. 2, exterior of right valve; fig. 3, dorsal view of paired valves. Locality TU 549, Chipola River, Calhoun County, Florida.

gately narrow valves, less pronounced posterior gape, and narrower and much more elongated pallial sinus suggesting that these earlier species may have been able to retract their siphons.

LOCALITY DATA

The following Tulane University locality numbers are all in the Chipola Formation, Calhoun County, Florida.

546. Ten Mile Creek, about 1-3/4 miles west of Chipola River (NE 1/4 Sec. 12, T1N, R10W) (=USGS 2212, "one mile west of Bailey's Ferry").
549. East bank of Chipola River, about 1/4 mile below Four Mile Creek (NE 1/4 Sec. 32, T1N, R9W).
817. South bank of Ten Mile Creek, large gully on property of Mr. A. Sexton (SE 1/4 Sec. 12, T1N, R9W).
819. Farley Creek, 0.2 mile west of bridge of Florida Highway 275 (SW 1/4 Sec. 21, T1N, R9W).
825. Farley Creek at abandoned mill about 1/4 mile west of bridge of Florida Highway 275 (SW 1/4 Sec. 21, T1N, R9W).
830. Ten Mile Creek at power line crossing about one mile west of Chipola River (SE 1/4 Sec. 12, T1N, R10W).

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December 5, 1985

REVIEW

PALYNOSTRATIGRAPHIE ET PALEOCLIMATOLOGIE DE L'EOCENE SUPERIEUR ET DE L'OLIGOCENE DU BASSIN DE PARIS, by Jean-Jacques Châteauneuf. Mémoire du Bureau de Recherches Géologiques et Minières, no. 116, Orleans, France; 1980, 360 pp., atlas of 31 pls., illus., paper, $59.00

This is a doctoral dissertation from l'Université Pierre et Marie Curie, Paris, published as a part of the B.R.G.M. memoir series. The work consists of a palynological inventory of the spores, pollens, and Dinoflagellate cysts from the upper Eocene and Oligocene sediments of the Paris Basin and environs and their relationship to the stratigraphy, depositional environments, and paleoclimatology of this important region. It is thorough and well illustrated.

—H.C.S.

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I. ABSTRACT

The calcareous nannoplankton in samples from the Paleocene Midway group of Alabama were examined and photographed using both a light misroscope and a scanning electron miscroscope. Twenty-seven species were identified, two of which are described as new. The nannoplankton distribution was used to correlate the Alabama Midway Group with standard Paleocene nannoplankton zonations resulting in the Pine Barren and McBryde members of the Clayton Formation being assigned to the *Cruciplacolithus tenuis* zone, and the Porters Creek Clay and the Matthews Landing Member being assigned to the *Cyclococcolithina robusta* zone. The nannoplankton distribution and abundances are related to the lithology and depositional environments of the Midway units. The Clayton and Porters Creek units contain certain species that are confined to or are more abundant in, particular lithologic facies. The very shallow-water deposits of the Naheola Formation are barren of nannoplankton.

II. INTRODUCTION

The Midway Group of Alabama consists of three formations (figure 1). These are, in order of stratigraphic sequence: (1) the Clayton Formation, which in central Alabama is divided into the lower Pine Barren Member and the upper McBryde Limestone Member; (2) the Porters Creek Clay, present only in western Alabama, with the Matthews Landing Marl Member at the top; and (3) the Naheola Formation, present only in central and western Alabama, divided into the lower Oak Hill Member and the upper Coal Bluff Marl Member.

Smith (1886) first used the term "Midway" in describing the strata exposed at Midway Landing on the Alabama River in Wilcox County, Alabama (figures 2, 3 and 4). This section at Midway Landing was described by Smith as having a few feet of black clay, which seemed equivalent to that at Black Bluff on the Tombigbee River (Porters Creek Clay), overlying about ten feet of gray, argillaceous limestone (the McBryde Limestone) with the nautiloid

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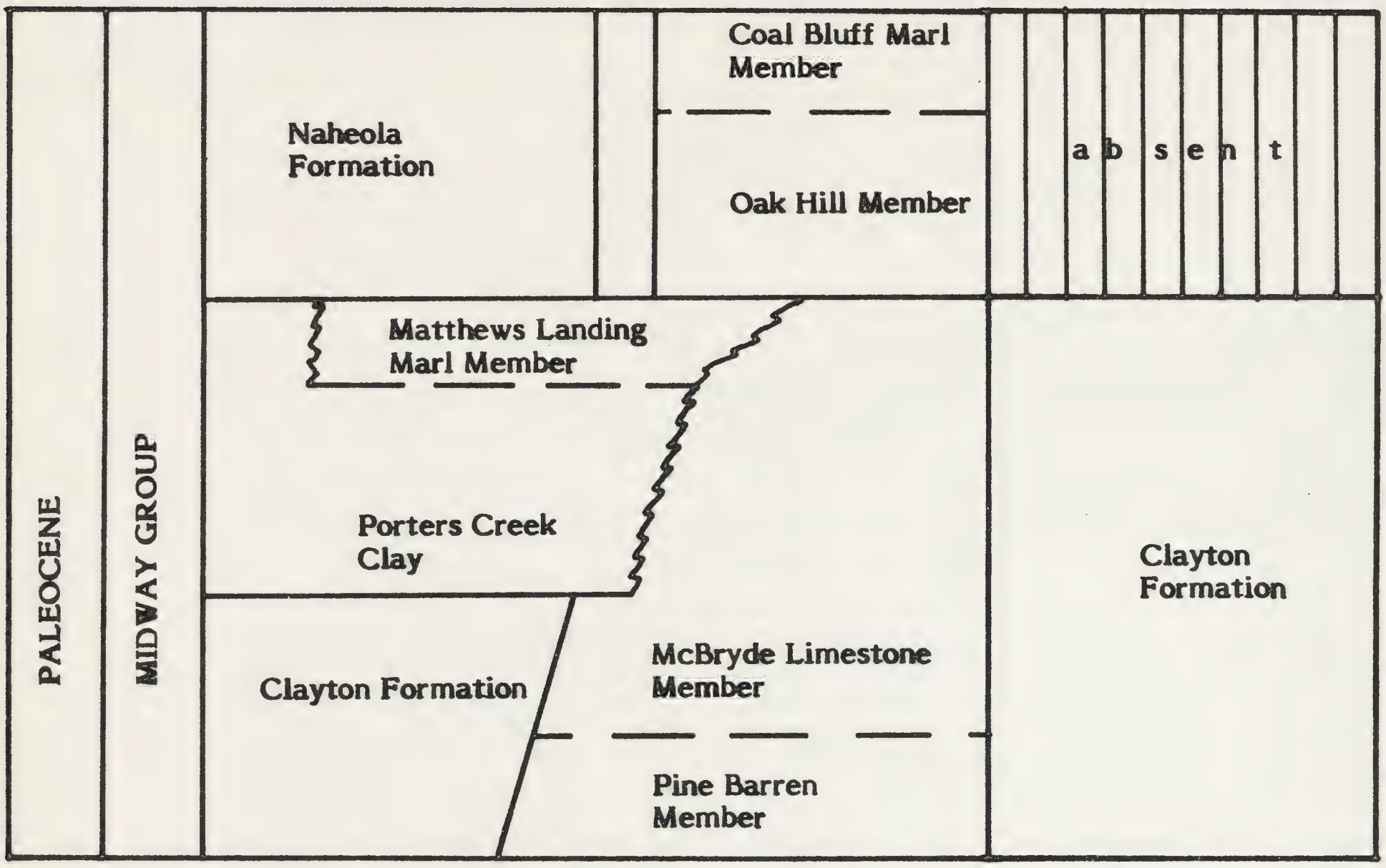

Figure 1 - Formations and Members of the Midway Group in Alabama

Enclimatoceras. LaMoreaux and Toulmin (1953) described this Midway section as part of the McBryde Limestone Member of the Clayton Formation, consisting of four hard calcareous claystone ledges interbedded with gray marl. Since the Alabama River has been dammed, only the uppermost claystone ledge is exposed.

The Clayton Formation was named for exposures near Clayton, Barbour County, Alabama by Smith (1892). Exposures at the type locality, in a Central of Georgia Railroad-cut one mile east of Clayton, consist of approximately 12 feet of dense, crystalline, gray limestone underlain by a tan, clayey sand (figures 2 and 5). LaMoreaux and Toulmin (1953) described the Clayton in Wilcox County, Alabama, as consisting of about 140 feet of massive limestone with some basal sand. In extreme western Alabama the Clayton Formation consists of less than 20 feet of limestone.

The Pine Barren Member of the Clayton Formation was named by MacNeil (1946) for strata exposed in roadcuts on the south side of Pine Barren Creek, along Alabama Highway 21 in Wilcox County (figures 2 and 4). In the upper part of this member is the "*Turritella* rock" of Smith (1894), which consists of a sandy yellow, crystalline limestone containing *Turritella alabamensis*. The lower part of the member is a gray calcareous silt with indurated ledges. In Wilcox County the Pine Barren Member has an estimated thickness of 125 feet (LaMoreaux and Toulmin, 1953).

The McBryde Limestone Member was named by MacNeil (1946) for exposures in roadcuts along Alabama Highway 21 in Wilcox County, approximately three miles west of McBryde Station. The station no longer exists but exposures can be found along Highway 21 at a locality 0.2 mile south of the intersection of Highway 21 and Highway 28 in Wilcox County (figures 2 and 4). At this locality the strata consist of approximately ten feet of light gray limestone, lying directly on the "*Turritella* rock" of the Pine Barren Member. The McBryde Limestone thickens to about 30 feet in eastern Wilcox County and Butler County (LaMoreaux and Toulmin, 1953).

Farther west it becomes more clayey and intertongues with the lower part of the Porters Creek Clay.

The Porter's Creek Clay was named by Safford (1864) for exposures west of Middleton, Tennessee. The equivalent deposits in Alabama were originally called the Sucarnoochee Clay by Smith (*in* Smith and Johnson, 1887) from exposures along Sucarnoochee Creek in Sumter County, Alabama. The type locality of the Sucarnoochee Clay is Black Bluff on the Tombigbee River below its confluence with Sucarnoochee Creek (figures 2 and 6). In western Alabama, the Porters Creek Clay consists of 350 feet of black, jointed clay with some limonitic concretions. Approximately 5 feet of glauconitic sand is present

Figure 2 - Counties containing type sections of the Midway Group in Alabama

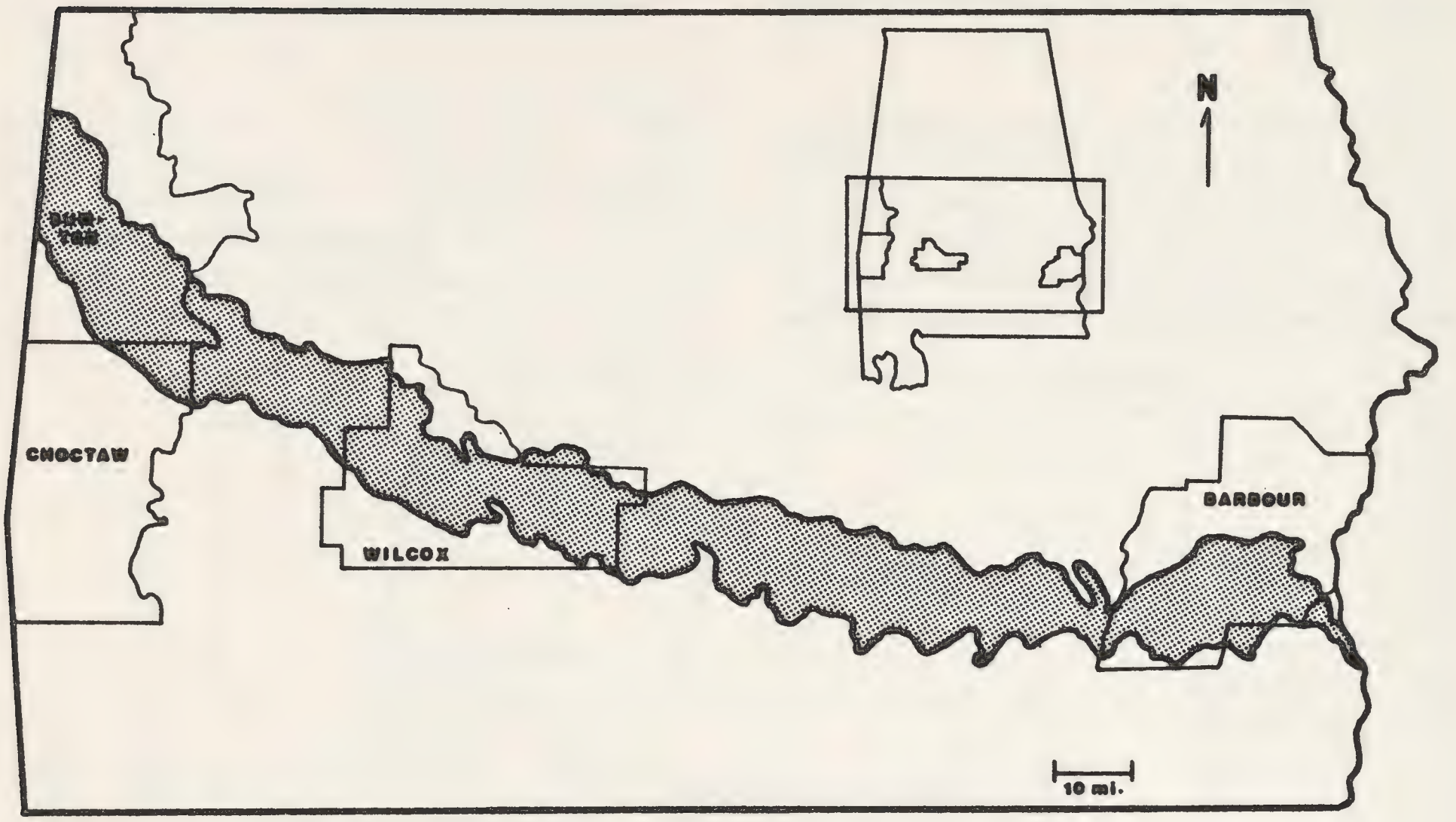

Figure 3 - Outcrop of the Midway Group in Alabama

at the top in the Matthews Landing Member. In central Alabama the Porters Creek Clay thins to about 100 feet and is more calcareous and fossiliferous. In this area, it contains some claystone and sandstone ledges. Farther eastward, beds correlative with the Porters Creek are included in the Clayton Formation (MacNeil, 1946).

The Matthews Landing Member was named by Smith (*in* Smith and Langdon, 1894) for exposures at Matthews Landing on the Alabama River in Wilcox County, Alabama (figures 2 and 4). Here the Matthews Landing Member is a gray-green, sandy marl approximately 20 feet thick. The marl thins westward to about five feet in Choctaw County. Due to the dam on the Alabama River only about ten feet of the Matthews Landing Member is exposed at present.

The Naheola Formation was named by Smith (*in* Smith and Johnson, 1887) for exposures at Naheola Landing on the Tombigbee River in Choctaw County, Alabama (figures 2 and 7). LaMoreaux and Toulmin (1953) described the exposures at this locality as consisting of 16 feet of tan to gray, sandy clay with indurated ledges overlying approximately four feet of black, sandy, blocky clay. The Naheola Formation thins eastward until it disappears east of Wilcox County. The dam on the Tombigbee River has resulted in most of the exposures at this locality being covered by water or river sediments. Only five feet of tan-gray, blocky clay underlain by five feet of black, blocky clay are now exposed during low water.

In western Alabama the Naheola Formation is divided into the lower Oak Hill Member and the upper Coal Bluff Member. The Oak Hill Member was named by Toulmin, LaMoreaux and Lanphere (1951) for exposures in roadcuts near the town of Oak Hill in Wilcox County, Alabama (figures 2 and 4). At this locality the Oak Hill consists of approximately 51 feet of gray-tan, laminated sandy and silty clay with carbonaceous layers. A thin bed of lignite marks the top of the Oak Hill Member. The Coal Bluff Marl Member was named by Toulmin (1944) for exposures at Coal Bluff on the Alabama River in Wilcox County. Toulmin described the section as consisting of gray, glauconitic, micaceous sand and clay at the top, with large glauconitic, sandstone concretions in a green sandy marl at the base. The section is now entirely under water. The Coal Bluff Member is exposed at the type locality of the Oak Hill Member and at Shoal Creek in Wilcox County (figures 2 and 4).

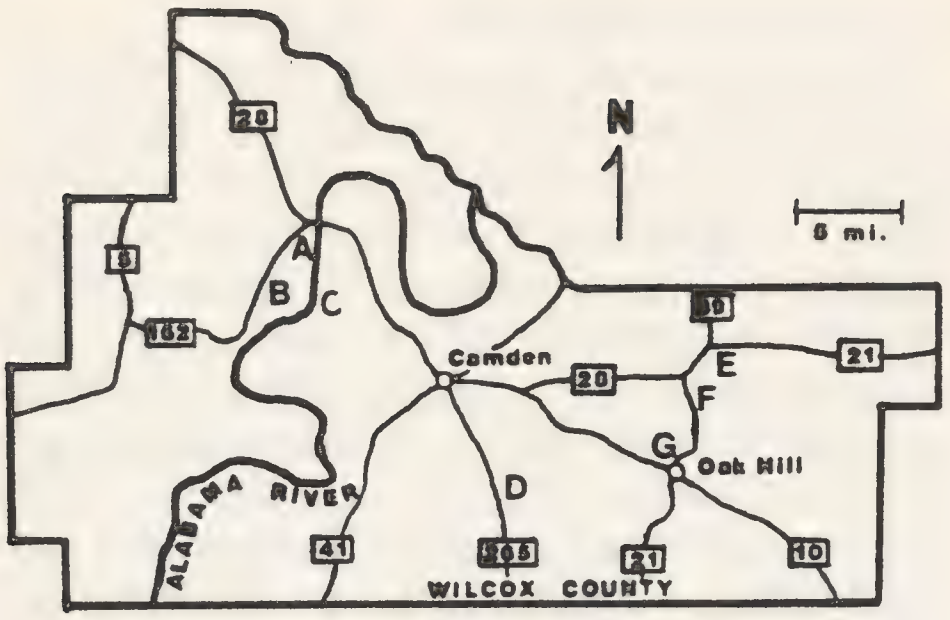

Figure 4 - Location of the sampled sections in Wilcox County.

A - Midway Landing
B - Secondary McBryde section
C - Matthews Landing
D - Secondary Coal Bluff section
E - Pine Barren section
F - McBryde section
G - Oak Hill and Coal Bluff sections

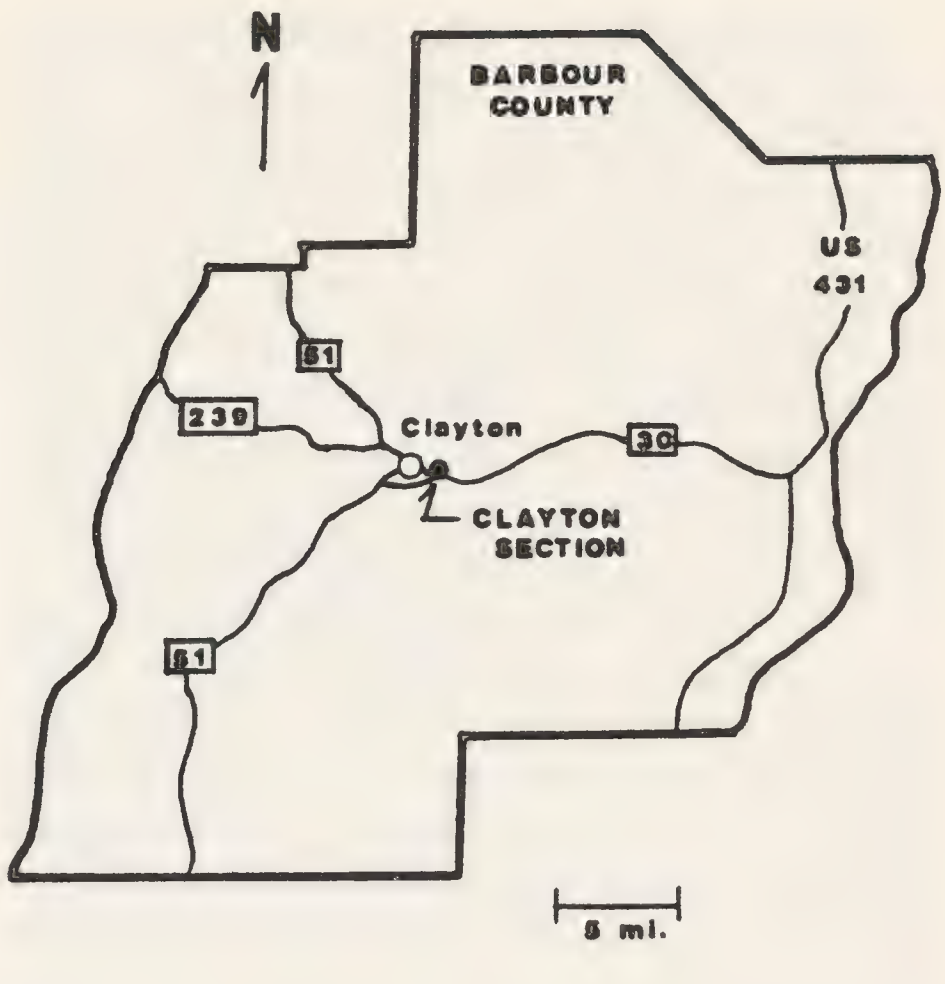

Figure 5 - Location of sampled section of the Clayton Formation in Barbour County, Alabama

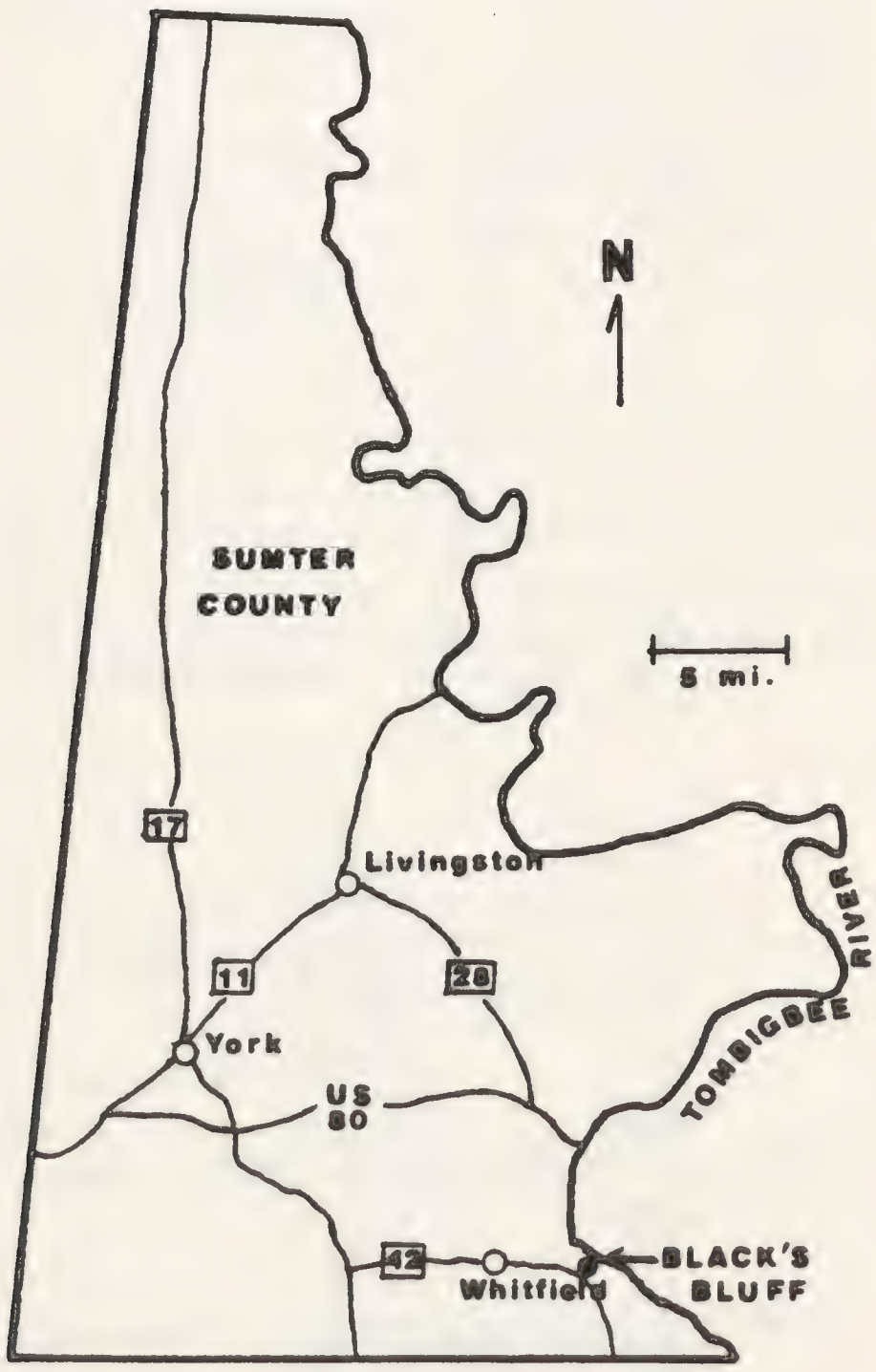

Figure 6 - Location of sampled section of the Porters Creek Formation in Sumter County, Alabama

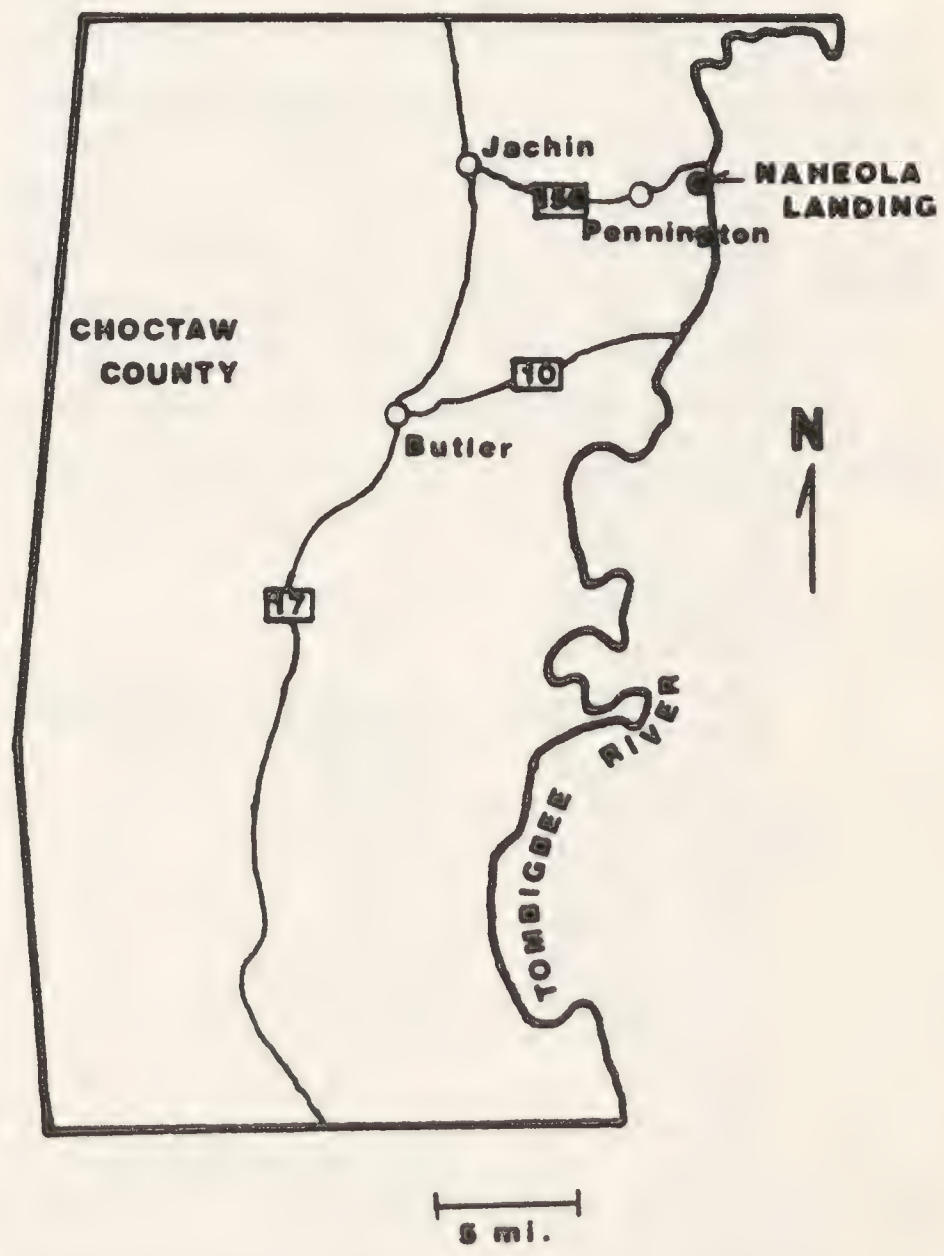

Figure 7 - Location of sampled section of the Naheola Formation in Choctaw County, Alabama

All of the Paleocene Midway units exposed in Alabama represent marine environments, as indicated by the paleontology (Toulmin, 1946) and the lithology (Murray, 1947). Bornhauser (1947) considered the calcareous deposits of the Lower Tertiary of Alabama and Mississippi to be transgressive deposits; with the shales and clays to be open marine inundative deposits and the sand units to be regressive deposits. The distinct lithologic changes upwards in the Alabama Midway section support this interpretation of the changing Lower Tertiary depositional environments. The basal Clayton Limestone underlies the marine clay of the Porters Creek, which in turn underlies the sandy, glauconitic, and lignitic restricted marine or swamp deposits of the Naheola Formation.

NacNeil (1946) stated that the Tertiary deposits of central and western Alabama are composed of deeper water facies than those of eastern Alabama. This is represented in the Paleocene Midway Group by the occurrence of a basal sand and sandy limestone in the Clayton Formation in easternmost Alabama. In central and western Alabama the basal Clayton contains a silty marl or clay. These facies relationships indicate that the central and western area of Alabama was more remote from the source of sediments than the areas on either side, and that the Tertiary shoreline extended from eastern Georgia to northern Mississippi (Toulmin, 1946).

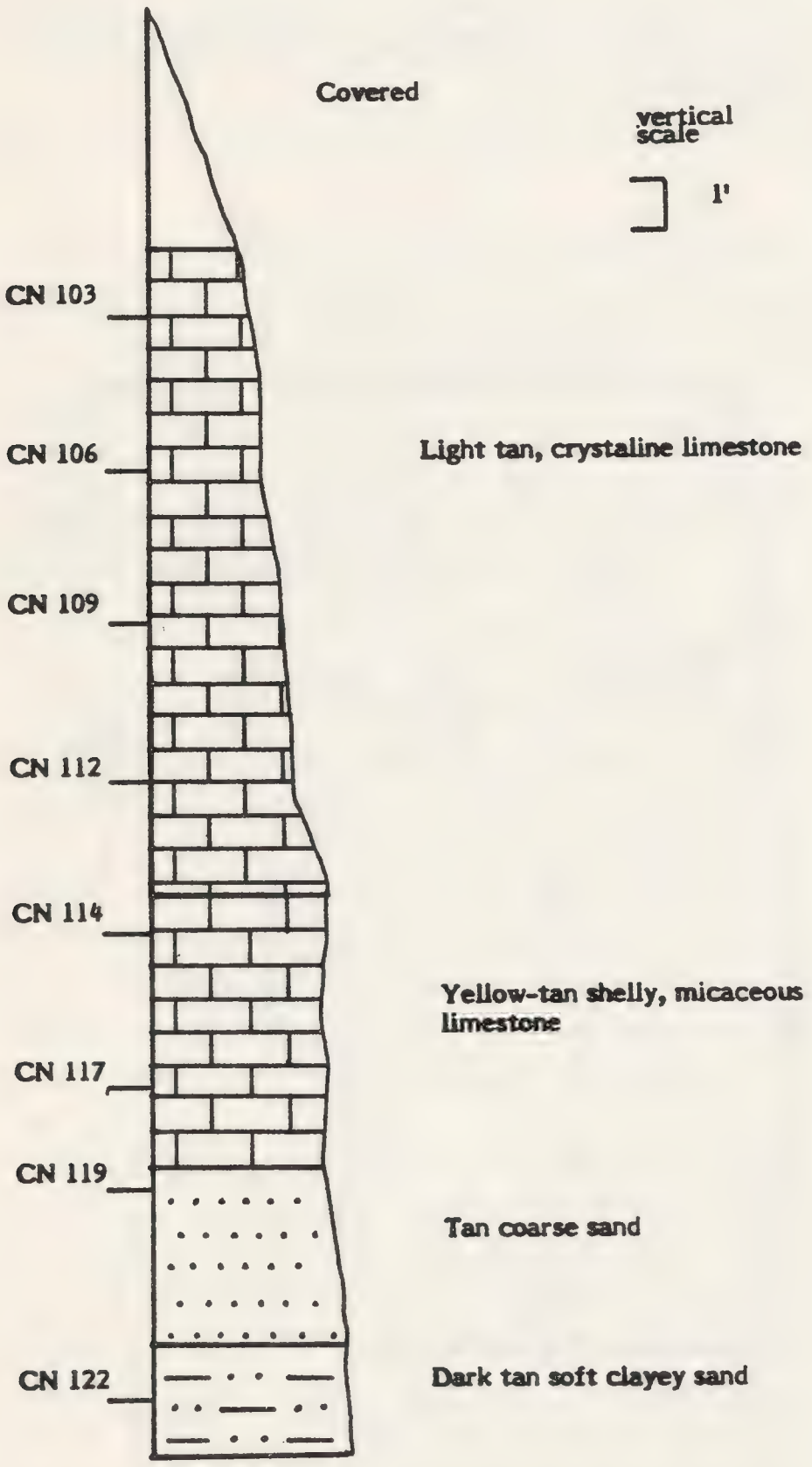

Figure 8 - Stratigraphic section of the Clayton Formation in Barbour County

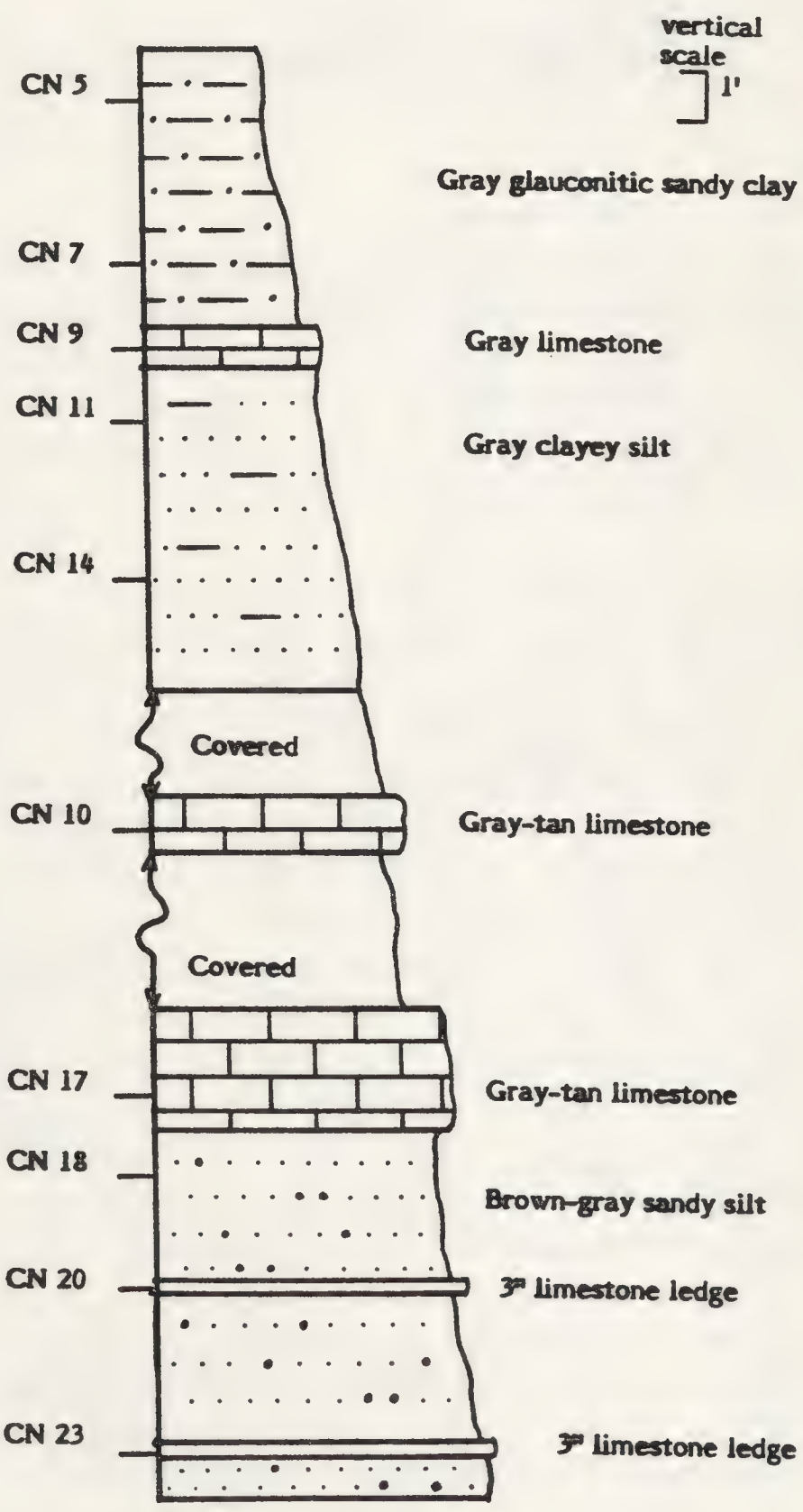

Figure 9 - Stratigraphic section of the Pine Barren Member in Wilcox County

III. PREVIOUS STUDIES

Several studies have reported on the calcareous nannoplankton of the Midway strata of Alabama. Bramlette and Martini (1964) described the calcareous nannoplankton in one sample from the McBryde Member of the Clayton Formation. Representatives of ten species of calcareous nannoplankton were found in that sample. They also stated that coccoliths occur in the Porters Creek Clay in sparse numbers. Hay and Mohler (1967) used samples from the McBryde and Pine Barren members of the Clayton Formation in their correlation of early Tertiary rocks from the U. S. Gulf Coast, France, and other worldwide locations. No list of the species found in the individual samples was included in that report. Ellis and Lohmann (1973) described a new species of coccolith, *Toweius petalosus*, in samples from the Clayton Formation and the Porters Creek Formation from Sumter County, Alabama. Cepek *et al.* (1968) reported finding no calcareous nannoplankton in samples from the Pine Barren Member of the Clayton Formation in Lowndes County, Alabama. Siesser (1983) reported on the Paleogene nannoplankton biostratigraphy of Alabama. This study included examination of samples from most of the Alabama Midway units.

There are several studies of the calcareous nannoplankton of the Paleocene from other locations. Sullivan (1964) discussed the calcareous nannoplankton of the Tertiary of California, including several new species. Hay and Mohler (1967) reported on the calcareous nannoplankton of the early Tertiary of France. Martini (1964) has used his studies of the calcareous nannoplankton of Europe to construct zones of calcareous nannoplankton of the Tertiary to be used in worldwide correlation. Hay *et al.* (1967) gave an excellent summary of other previous works on Tertiary nannoplankton. The work of Perch-Neilsen (1969, 1971, 1977, etc.) on Tertiary nannofossils includes studies of the Paleocene from Europe and several Deep Sea Drilling Project locations.

Subdivision of the Paleocene strata using calcareous nannoplankton has been attempted by several authors including Martini (1959, 1961, 1970, 1971), Stradner (1959; *in* Gohrbandt, 1963), Bramlette and Sullivan (1961), Hay and Mohler (1965, 1967), and Sullivan (1964). The more recent work of Hay *et al.* (1967) utilized previous studies to produce more useful zones based on continental and marine sediments. Gartner (1971) erected zones (see figure 18), modified from those of Hay, which he correlated with planktonic foraminiferal zones adapted from Blow (1969).

Gartner (1971) pointed out that calcareous nannoplankton zones generally are based on samples from widely separated geographic areas and represent different lithologies and, in may cases, different depositional environments. For this reason, Gartner speculated that such zonations have inherent weaknesses, which he attempted to overcome by using cosmopoli-

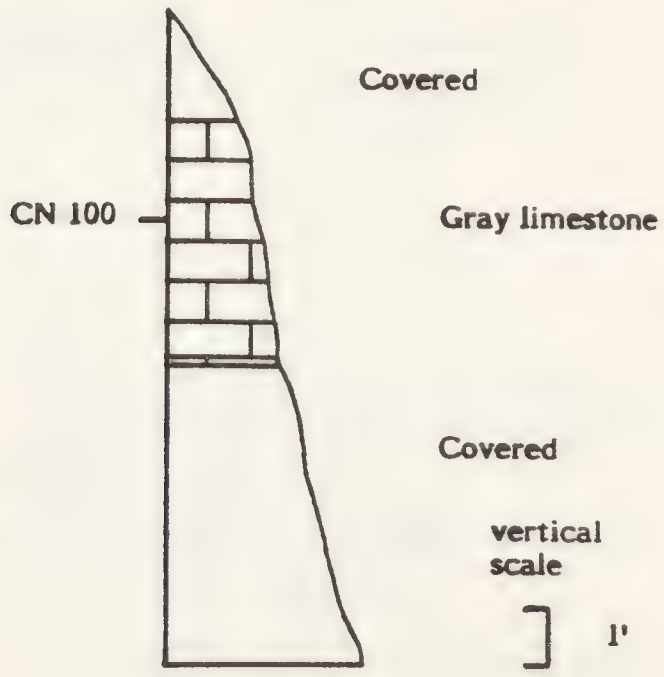

Figure 10 - Stratigraphic section of the McBryde Limestone Member at type locality in Wilcox County

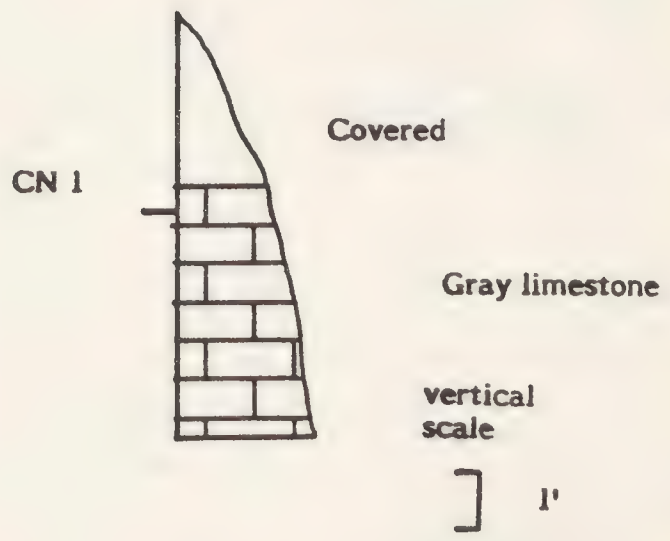

Figure 11 - Stratigraphic section of the McBryde Limestone Member at secondary location in Wilcox County (Sample CN 78 taken from 4 inch ledge of McBryde Limestone at Midway type locality)

tan species when possible as zonal indicators. His modification of the Hay *et al.* (1967) zonation consisted of recognizing one new mid-Paleocene zone, the *Cyclococcolithina robusta* zone, and defining the Paleocene-Eocene boundary, based on calcareous nannoplankton as falling within the *Marthasterites contortus* zone. Hay *et al.* did not base the Paleocene-Eocene boundary on the calcareous nannoplankton, but stated: "The Paleocene-Eocene boundary, as defined on the basis of evolutionary series of larger foraminifera in Europe, lies within the *Marthasterites tribrachiatus* zone."

The Paleocene calcareous nannoplankton zones of Gartner (1971) are based on the first or last occurrences of different calcareous nannoplankton species and are defined as follows:

MARKALIUS ASTROPORUS Zone - The interval from the first occurrence of *Markalius astroporus* to the first occurrence of *Cruciplacolithus tenius.* Other species common in this zone are;

Braarudosphaera bigelowi
Braarudosphaera discula
Biantholitus sparsus

CRUCIPLACOLITHUS TENUIS Zone - The interval from the first occurrence of *Cruciplacolithus tenuis* to the first occurrence of *Cyclococcolithina robusta.* The species of the *Markalius astroporus* zone are still present along with *Chiasmolithus danicus.*

CYCLOCOCCOLITHINA ROBUSTA Zone - The interval from the first occurrence of *Cyclococcolithina robusta* to the first occurrence of *Fasciculithus tympaniformis.* Other species common in this zone are:

Markalius astroporus
Cruciplacolithus tenuis
Ellipsolithus macellus
Toweius craticulus
Chiasmolithus bidens

FASCICULITHUS TYMPANIFORMIS Zone - The interval from the first occurrence of *Fasciculithus tympaniformis* to the first occurrence of *Heliolithus kleinpelli. The species of the Cruciplacolithus tenuis* and *Cyclococcolithina robusta* zones

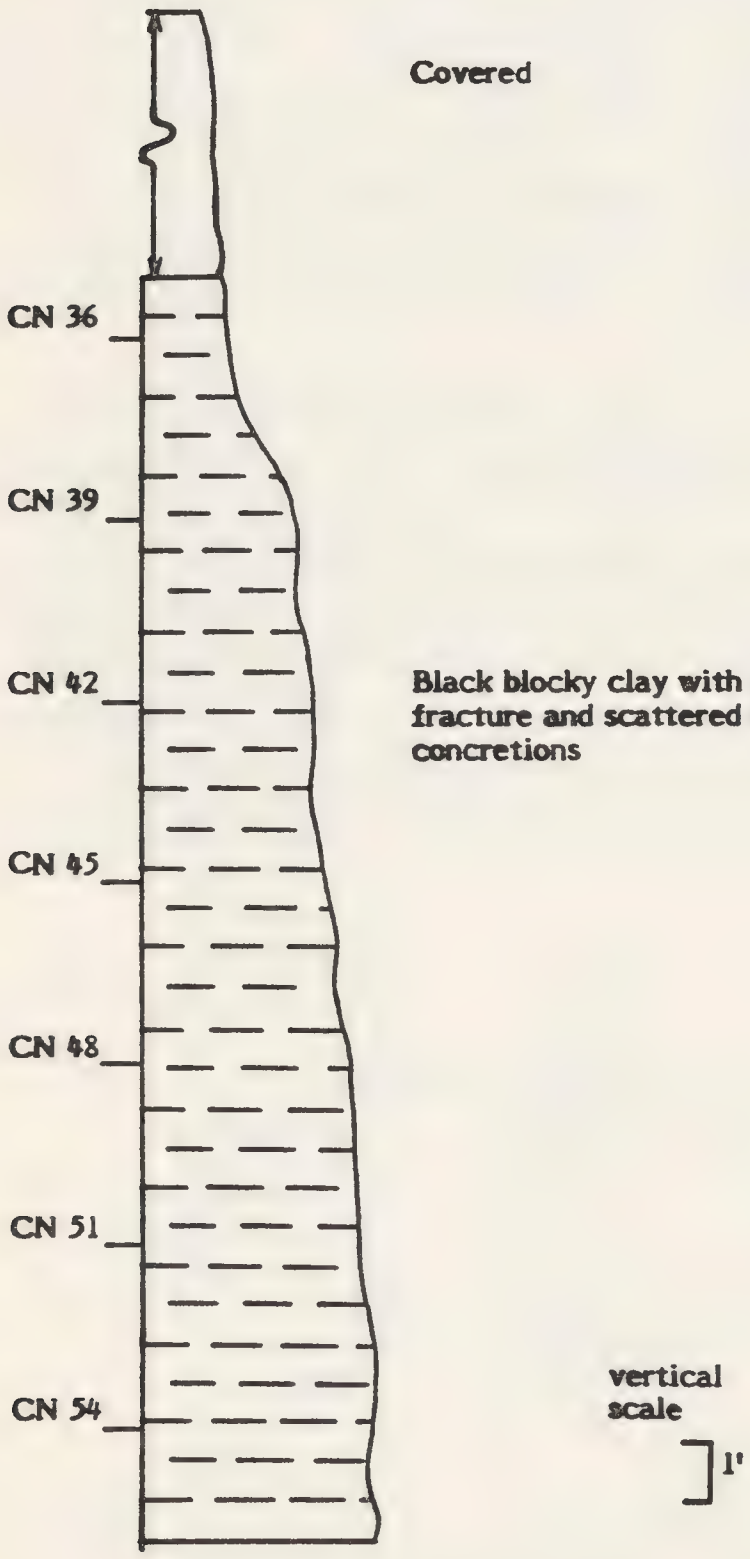

Figure 12 - Stratigraphic section of the Porters Creek Formation in Sumter County

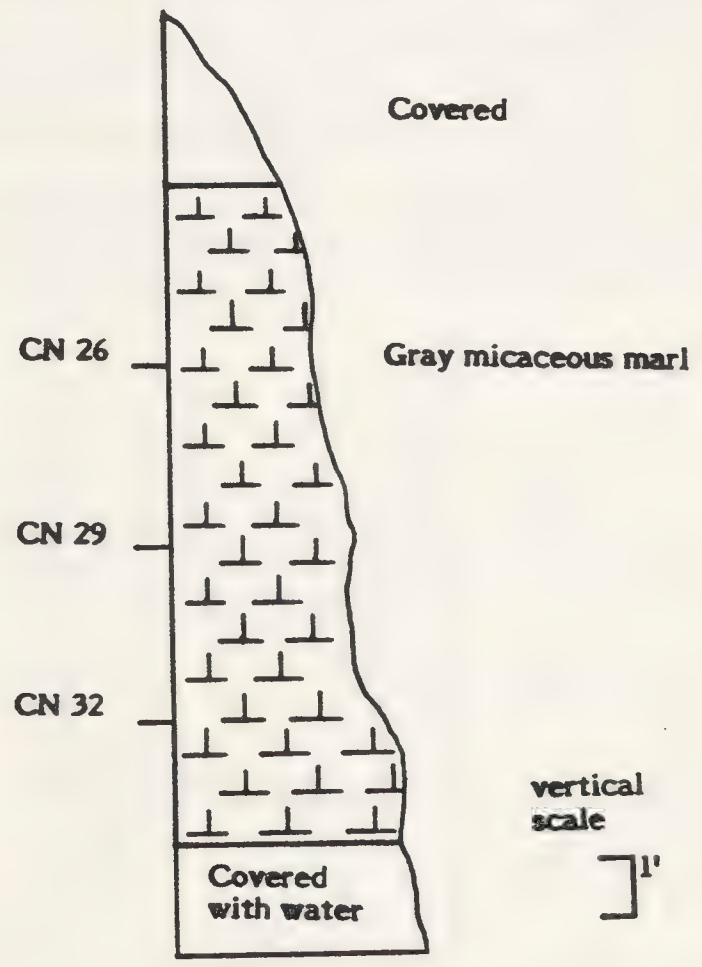

Figure 13 - Stratigraphic section of the Matthews Landing Member in Wilcox County

are still present. Other species common in this zone are:

Heliorthus concinnus
Chiasmolithus consuetus

HELIOLITHUS KLEINPELLI Zone - The interval from the first occurrence of *Heliolithus kleinpelli* to the first occurrence of *Discoaster gemmeus*. Other species common in this zone are:

Braarudosphaera bigelowi
Chiasmolithus danicus
Cyclococcolithina robusta
Fasciculithus tympaniformis
Chiasmolithus bidens
Heliorthus concinnus
Chiasmolithus consuetus

DISCOASTER GEMMEUS Zone - The interval from the first occurrence of *Discoaster gemmeus* to the first occurrence of *Heliolithus riedeli*. The species of the *Heliolithus kleinpelli* zone are still present except for *Heliolithus kleinpelli*. Also common in this zone is *Dicoaster helianthus*.

HELIOLITHUS RIEDELI Zone - The interval from the first occurrence of *Heliolithus riedeli* to the first occurrence of *Discoaster multiradiatus*. The species of the *Discoaster gemmeus* zone are still present. Other species common in this zone are:

Discoater delicatus
Discoaster nobilis
Discoaster limbatus
Zygodiscus plectopons

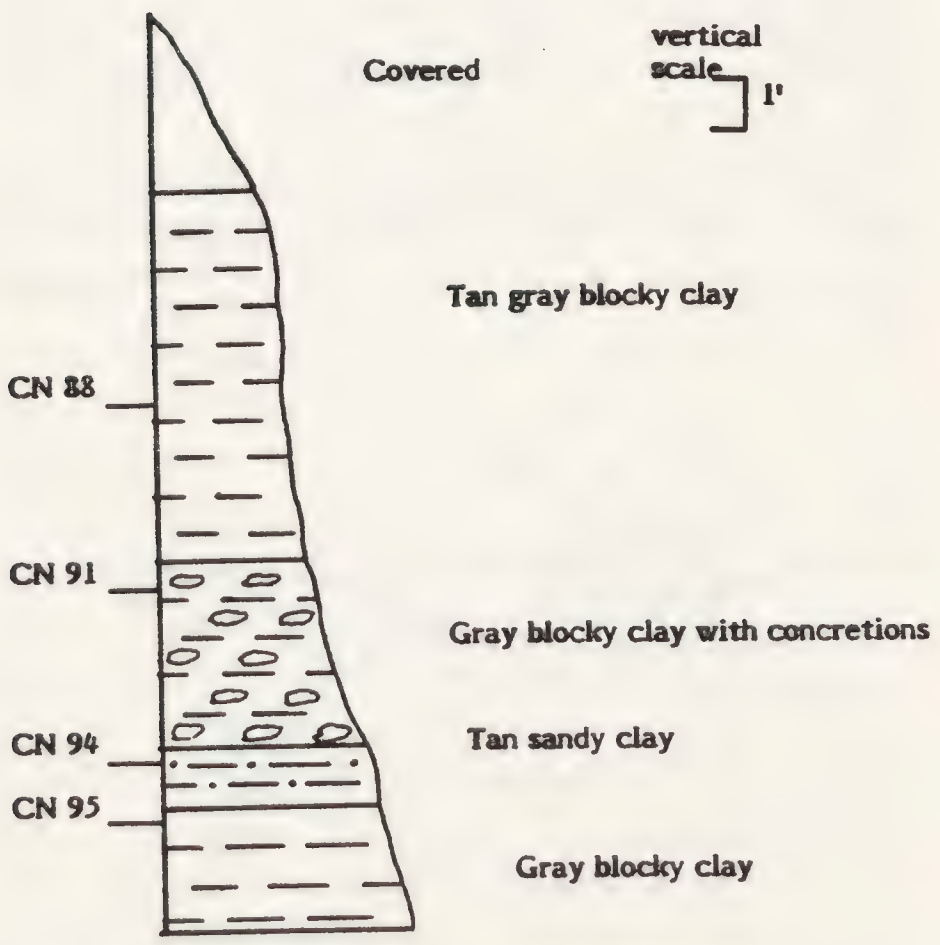

Figure 14 - Stratigraphic section of the Naheola Formation in Choctaw County

Ellipsolithus distichus
Fasciculithus involutus

DISCOASTER MULTIRADIATUS Zone - The interval from the first occurrence of *Discoaster multiradiatus* to the first occurrence of *Marthasterites bramletti*. Species common in this zone are:

Discoaster gemmeus
Discoaster perpolitus
Discoaster lenticularis
Discoaster mediosus
Discoaster delicatus
Discoaster nobilis
Discoaster limbatus
Zygodiscus plectopons
Clathrolithus ellipticus
Chiasmolithus danicus
Cyclococclithina robusta
Chiasmolithus consuetus
Fasciculithus tympaniformis

MARTHASTERITES CONTORTUS Zone - The interval from the first occurrence of *Marthasterites bramlettei* to the last occurrence of *Marthasterites contortus*. Species common in this zone are:

Discoaster binodosus
Discoaster diastypus

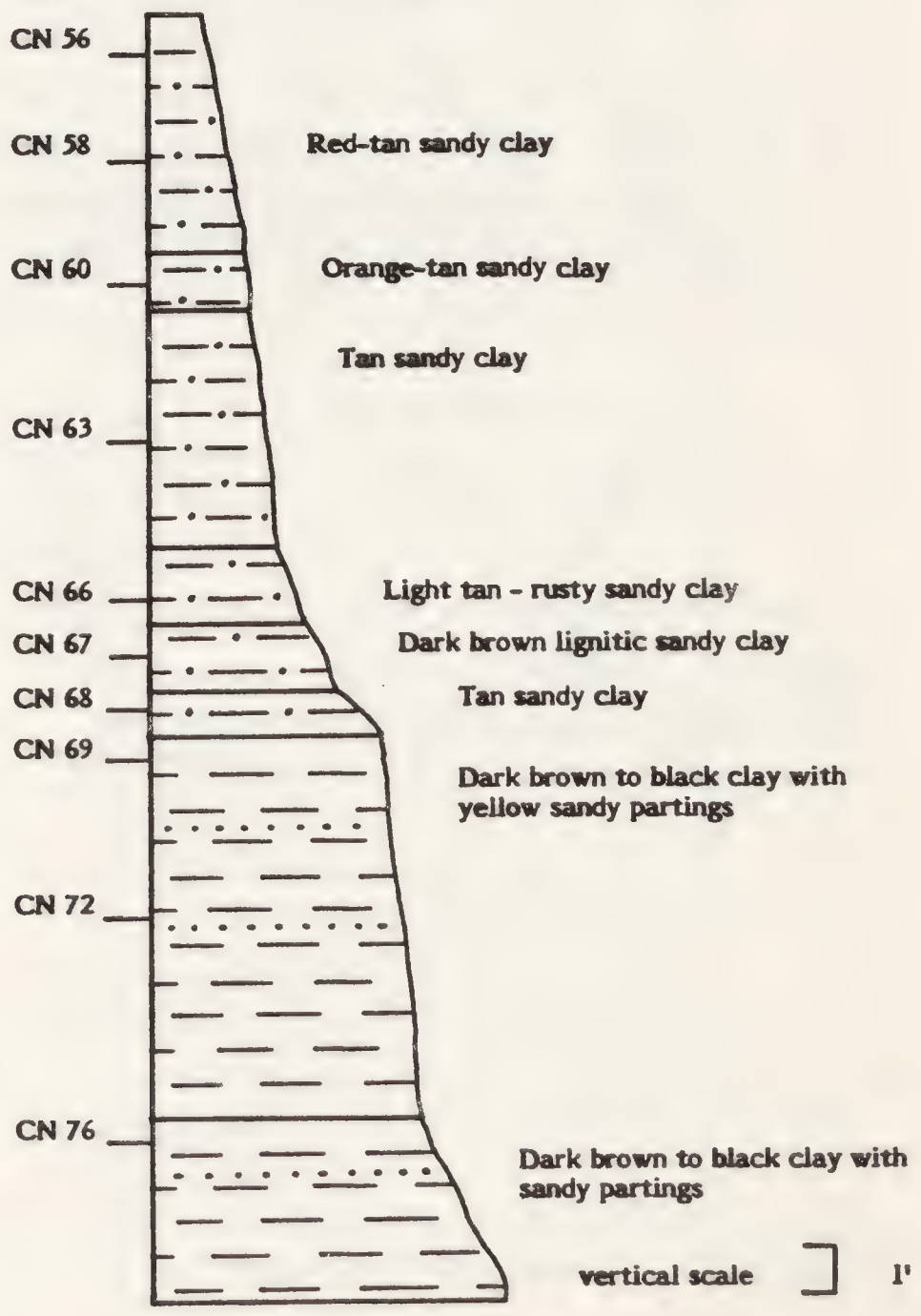

Figure 15 - Stratigraphic section of the Oak Hill Member in Wilcox County

Discoaster perpolitus
Discoaster multiradiatus
Discoaster gemmeus
Discoaster lenticularis
Discoaster nobilis
Zygodiscus plectopons
Chiasmolithus danicus
Fasciculithus tympaniformis
Cyclococcolithina robusta

The zonation of Martini (1970, 1971) has modified the previous zonations by erecting two zones between the *Cruciplacolithus tenuis* and *Fasciculithus tympaniformis* zones: 1) the *Chiasmolithus danicus* zone, and 2) the *Ellipsolithus macellus* zone. Martini assigned numbers (NP-1, etc.) to all of the nannoplankton zones (see figure 19) and correlated them to existing foraminiferal zones. Siesser (1983) assigned the following zones of Martini to the corresponding Alabama Midway units: Pine Barren, NP-1 and 2; McBryde, Porters Creek and Matthews Landing, NP-3 and 4; Naheola and Coal Bluff, NP-5.

Paleocene foraminiferal zonations have been published, based on studies by Bolli (1957), Hay (1960), Subbotina (1953), etc. Such works show varied placement of the Paleocene-Eocene boundary. Loeblich and Tappan (1957) established zones shown in figure 20 based on the foraminifers in samples from the Alabama Midway strata. Their results differ from the Paleocene zonation of other workers. Berggren (1965) used the results of previous workers to produce a correlation of the Alabama Midway Group with planktonic foraminiferal zones (see figures 20). Blow (1969), in his widely used foraminiferal zonations, divided the Paleocene into five planktonic zones (see figure 18).

Comparing the Gulf Coast Paleocene foraminiferal zonations of Loeblich and Tappan, and Berggren to the standard divisions of Blow and correlating these to the standard nannoplankton zones of Gartner (see figure 21), the following conclusions can be presented:

(1) The Clayton Formation is within the P1 zone of Blow, or the *Markalius astroporus* and *Cruciplacolithus tenuis* nannoplankton zones.

(2) According to Berggren's zonation, the lower section of the Porters Creek Clay correlates with zone P 2, or the *Cruciplacolithus tenuis* and *Cyclococcolithina robusta* nannoplankton zones.

(3) The Matthews Landing Member of the Porters Creek Clay, and the Naheola Formation correlate with the P 3 foraminiferal zone, or the *Cyclococcolithina robusta, Fasciculithus tympaniformis*, and *Heliolithus kleinpelli* nannoplankton zones.

Hay and Mohler (1967), examining samples from the McBryde and Pine Barren members of the Clayton Formation, recognized three of Gartner's (1971) nannoplankton zones. The *Markalius astroporus* zone and the *Cruciplacolithus tenuis* zone contain the nannofossil species common in each. The *Fasciculithus tympaniformis* zone contains all of the species characteris-

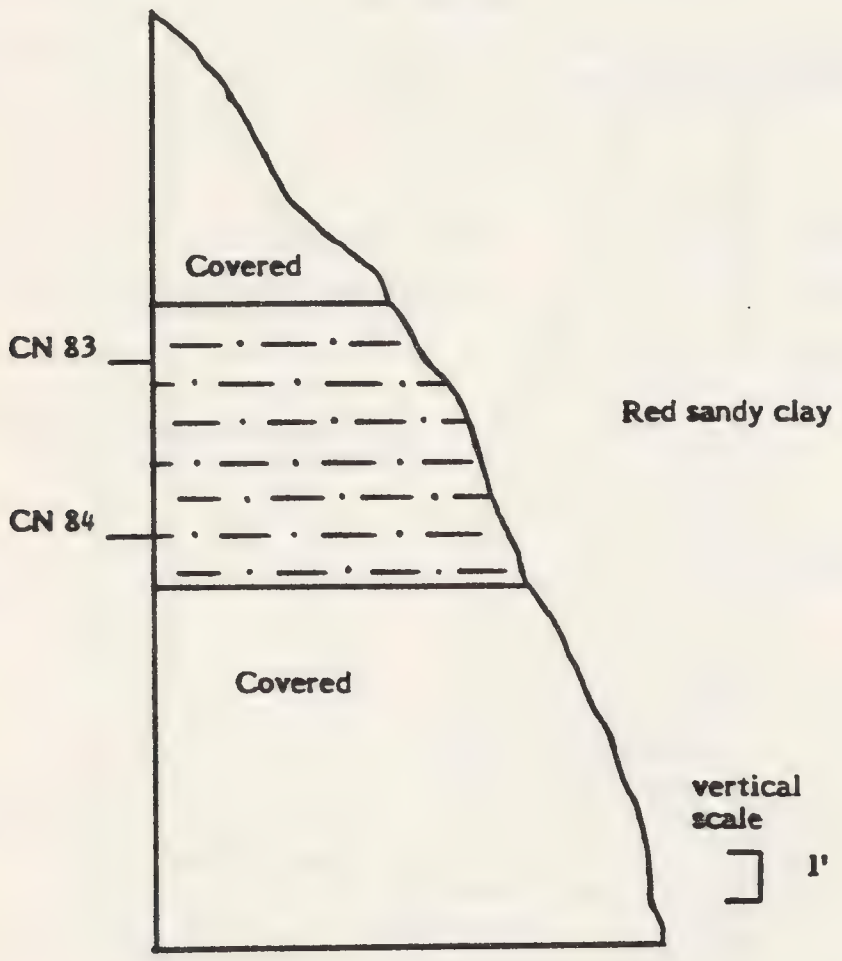

Figure 16 - Stratigraphic section of the Coal Bluff Member at Oak Hill locality in Wilcox County

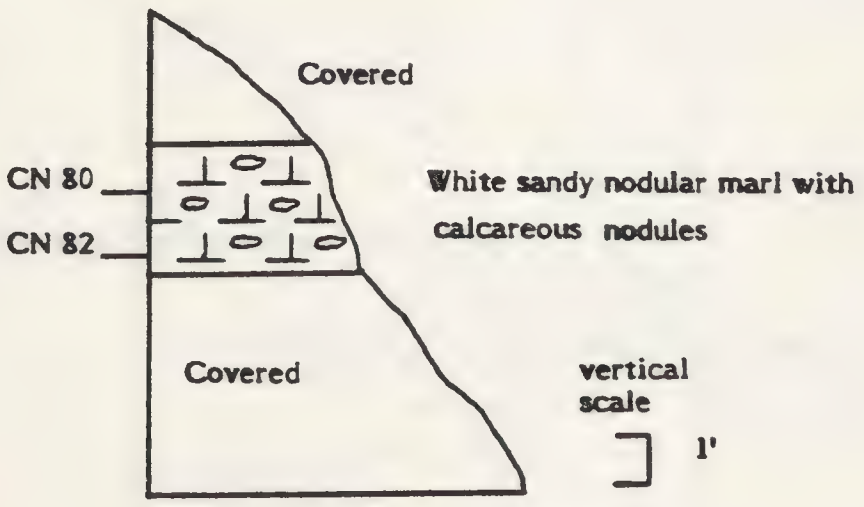

Figure 17 - Stratigraphic section of the Coal Bluff Member at Shoal Creek in Wilcox County

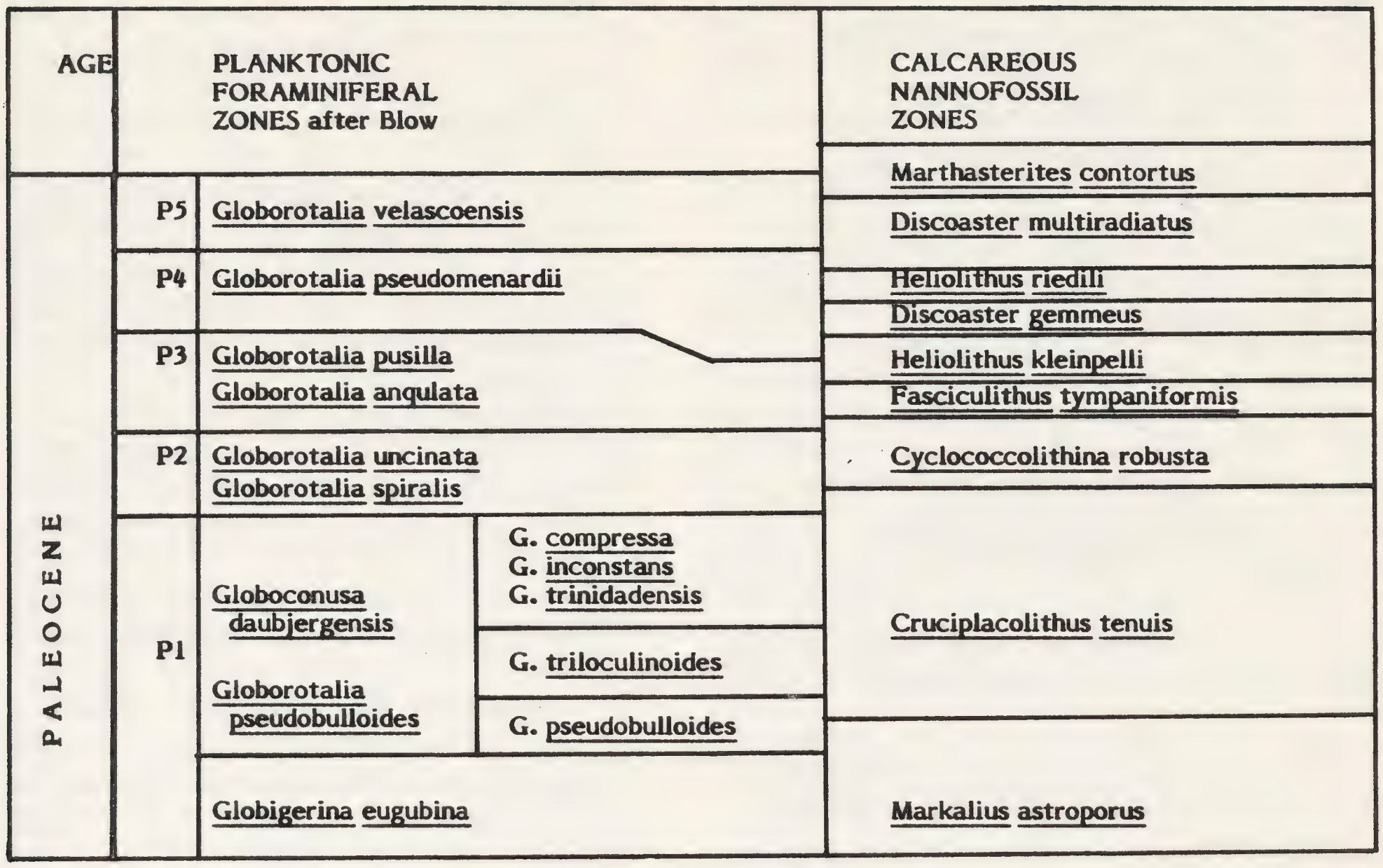

Figure 18 - Paleocene Calcareous Nannoplankton Zonation and corresponding foraminiferal zonations (after Gartner 1971)

tic of Gartner's zone except for *Fasciculithus tympaniformis*. These occurrences are compared by the author with the standard foraminiferal zonations as shown in figure 22. The Clayton Formation is correlated with the aforementioned nannoplankton zones and the P 2 and P 3 foraminiferal zones of Blow.

IV. LOCATIONS OF SAMPLED SECTIONS

The samples used in this study include material collected from the type sections or type localities of all formations and members of the Alabama Midway Group, with the exception of the Coal Bluff Member of the Naheola Formation. The type section of the Coal Bluff Member is inaccessible because of raised river levels but samples of this member were collected from other locations. Figure 3 shows the outcrop of the Paleocene Midway Group in Alabama and the counties where the type localities are studied. Figures 5-7 show the locations of the sections sampled. Samples were taken at one foot intervals from each section. The letters CN before sample numbers indicate samples collected and processed for calcareous nannofossils.

The following list gives the location of the sampled sections and refers to the map and figures illustrating each section. The numbers and the stratigraphic levels for each of the collected samples used in the present study are shown on the illustrated stratigraphic sections.

Midway type section - Midway Landing, Alabama River, Wilcox County, Alabama; approximately 2 miles south of Highway 28 bridge crossing the Alabama River.
(McBryde Limestone)
Tulane University locality number 1181. Sample CN 78; Figure 4.

Clayton Formation type locality - section in Central of Georgia Railroad cut one mile east of Clayton, Barbour County, Alabama.
Tulane University locality number 1178. Samples CN 103-122; Figures 5 and 8.

Pine Barren Member locality - Roadcuts on the south side of Pine Barren Creek on Alabama Highway 21, one

PALEOCENE	NP 9	Discoaster multiradiatus
	NP 8	Heliolithus riedeli
	NP 7	Discoaster gemmeus
	NP 6	Heliolithus kleinpelli
	NP 5	Fasciculithus tympaniformis
	NP 4	Ellipsolithus macellus
	NP 3	Chiasmolithus danicus
	NP 2	Cruciplacolithus tenuis
	NP 1	Markalius astroporus

Figure 19 - Paleocene Calcareous Nannoplankton Zones of Martini (1970)

mile south of the junction of Highway 21 with highway 89, Wilcox County, Alabama.
Tulane University locality number 1179. Samples CN 5-23; Figures 4 and 9.

McBryde Member type locality - Roadcut on Alabama Highway 21, 0.2 mile south of the junction of Highway 21 with Highway 28, Wilcox County, Alabama.
Tulane University locality number 1180. Samples CN 96-102; Figures 4 and 10.

McBryde Member secondary locality - Creek bed just off of Alabama highway 162 one mile south of the junction of Highway 162 with Highway 28, Wilcox County, Alabama.
Tulane University locality number 1186. Samples CN 1-4; Figures 4 and 11.

Midway Landing type section (See Midway type section above).

Porters Creek Clay - type locality of Sucarnoochee Clay, Black Bluff on the Tombigbee River approximately 2.5 miles east of Whitfield, Sumter County, Alabama.
Tulane University locality number 1182. Samples CN 36-55; Figures 6 and 12.

Matthews Landing Marl Member type locality - Matthews Landing on the Alabama River, Wilcox County, Alabama; approximately 5 miles southeast of Canton Bend, Alabama.
Tulane University locality number 1183. Samples CN 24-35; Figures 4 and 13.

Naheola Formation type locality - Naheola Landing on the Tombigbee River just south of the pump house of the American Can Company, 2 miles east of Pennington, Choctaw County, Alabama.
Samples CN 85-95; Figures 7 and 14.

Oak Hill Member type locality - 0.5 mile northeast of Oak Hill post office on Highway 21, Wilcox County, Alabama.
Tulane University locality number 1185. Samples CN 56-77; Figures 4 and 15.

Coal Bluff Marl Member - (type locality not accessible) samples from exposures above the Oak Hill Member at the type locality of the Oak Hill Member.
Tulane University locality number 1185. Samples CN 83-84; Figures 4 and 16.

Coal Bluff Marl Member secondary locality - Roadcut on Highway 265 at Shoal Creek, 5.5 miles south of Camden, Wilcox County, Alabama.
Tulane University locality number 1187. Samples CN 79-82; Figures 4 and 17.

V. TECHNIQUES AND PROCEDURES

A portion of each of the samples collected from the Alabama Midway sections was processed to concentrate the coccolith-size fraction. This was accomplished by first removing the outer material from the rock fragment to ensure a non-contaminated portion. The cleaned sample was then crushed with a mortar and pestle. The powder was placed in a 50 ml beaker to which approximately 30 ml of buffering solution was added. An ultrasonic cleaner was then used to break up the sample and disperse the clay-size material. The beaker was allowed to stand for two minutes to settle the sand-size material. The remaining suspension was decanted into a second beaker and allowed to stand for two hours to concentrate the finer sized material. The remaining sus-

pension was poured off and distilled water was added to the remaining sediment. The sample was allowed to settle for another two hours before the remaining water was decanted and discarded. This resulted in a sample free from any buffering solution, which could cause crystals to develop when the sample is dried.

Permanent mounts of selected samples were then prepared for examination with the Zeiss Photo microscope using Caedax as a mounting medium. Permanent slides were made of every third sample in each of the Midway sections, or for each sample where a change in lithology was evident. A second slide was prepared of each sample and examined to reduce the chance that a single slide could be of poor quality with a resulting unfavorable specimen count. A standard count of 150 specimens or 5 traverses was made on each of the two slides prepared for each sample. Photographs were taken of representatives of each of the species present using Kodak High Contrast Copy film. A Scanning Electron Microscope was also used to examine and photograph representatives of species seen in the light microscope.

VI. RESULTS AND CONCLUSIONS

Samples examined from the Midway Group of Alabama contained representatives of 27 species from 18 genera of calcareous nannoplankton. Two are new species described herein; the other species are forms previously described from the Paleocene or the Cretaceous. The five Cretaceous species are apparently reworked specimens; four of these are confined to the basal Pine Barren Member of the Clayton Formation. Figure 23 shows the distribution and abundances of the species represented in the sampled sections.

The Pine Barren Member of the Clayton Formation contained representatives of 21 species from 15 genera of calcareous nannoplankton. Ten of these species are con-

			Loeblich and Tappan (1957)	Berggren (1965)
PALEOCENE	SABINE	Salt Mountain Formation	Globorotalia velascoensis-spiralis subzone	Globorotalia velascoensis zone
	MIDWAY	Naheola Formation — Coal Bluff Member	Globorotalia pseudo-bulloides subzone	Globorotalia pusilla-pusilla / Globorotalia angulata zone
		Naheola Formation — Oak Hill Member		
		Naheola Formation — Matthews Landing Member		
		Porters Creek Formation		Globorotalia uncinata zone
		Clayton Formation — McBryde Member	Globorotalia compressa	
		Clayton Formation — Pine Barren Member	Globigerinoides daubjergensis zone	Globigerina daubjergensis / Globorotalia trinidadensis zone

Figure 20 - Foraminiferal Zonation by Loeblich and Tappan, and Berggren of the Gulf Coast Paleocene

fined to the Pine Barren Member. These species are:

Braarudosphaera turbinea
Coccolithus species
Cribrosphaerella ehrenbergii
Cruciplacolithus tenuis var. c
Eiffelithus turriseiffeli
Heliorthus denticulatus
Markalius reinhardtii
Prediscosphaera cretacea
Toweius petalosus
Prinsius cf. *P. martinii*

Common species, or those appearing in more than fifty percent of the samples of the Pine Barren Member, are:

Chiasmolithus californicus
Coccolithus species
Cruciplacolithus tenuis var. a
Cruciplacolithus tenuis var. b
Markalius reinhardtii
Neococcolithes protenus
Thoracosphaera multiperforata
Tharacosphaera saxea
Thoracosphaera cf. *T. imperforata*
Zygodiscus sigmoides
Prinsius cf. *P. martinii*

Of these, the four that appear in greatest abundance in the Pine Barren Member samples are *Coccolithus* species, *Cruciplacolithus tenuis* var. a, *Thoracosphaera* cf. *T. imperforata*, and *Zygodiscus sigmoides*.

Three relationships are apparent in the Pine Barren Member:

1) The samples composed of sandy clay and silts generally yield more abundant counts of total specimens than the limestone samples;

(2) *Chiasmolithus californicus* is common in the Pine Barren Member and is confined to samples consisting of clayey silts, but is found in the overlying McBryde Limestone, indicating that no lithologic relationship between this species and associated sediments seems to exist;

(3) *Toweius petalosus* is present only in the lower half of the Pine Barren section and is more abundant near the bottom of the section. There is no apparent relation between the other species present or their abundances and the lithology of the samples.

The McBryde Member of the Clayton Formation contained representatives of 21 species from 10 genera of nannoplankton. Five species are confined to the McBryde Member:

Prinsius dimorphosus
Chiasmolithus consuetus
Coccolithus crassus var. a
Coccolithus crassus var. b
Coccolithus orbiculatus

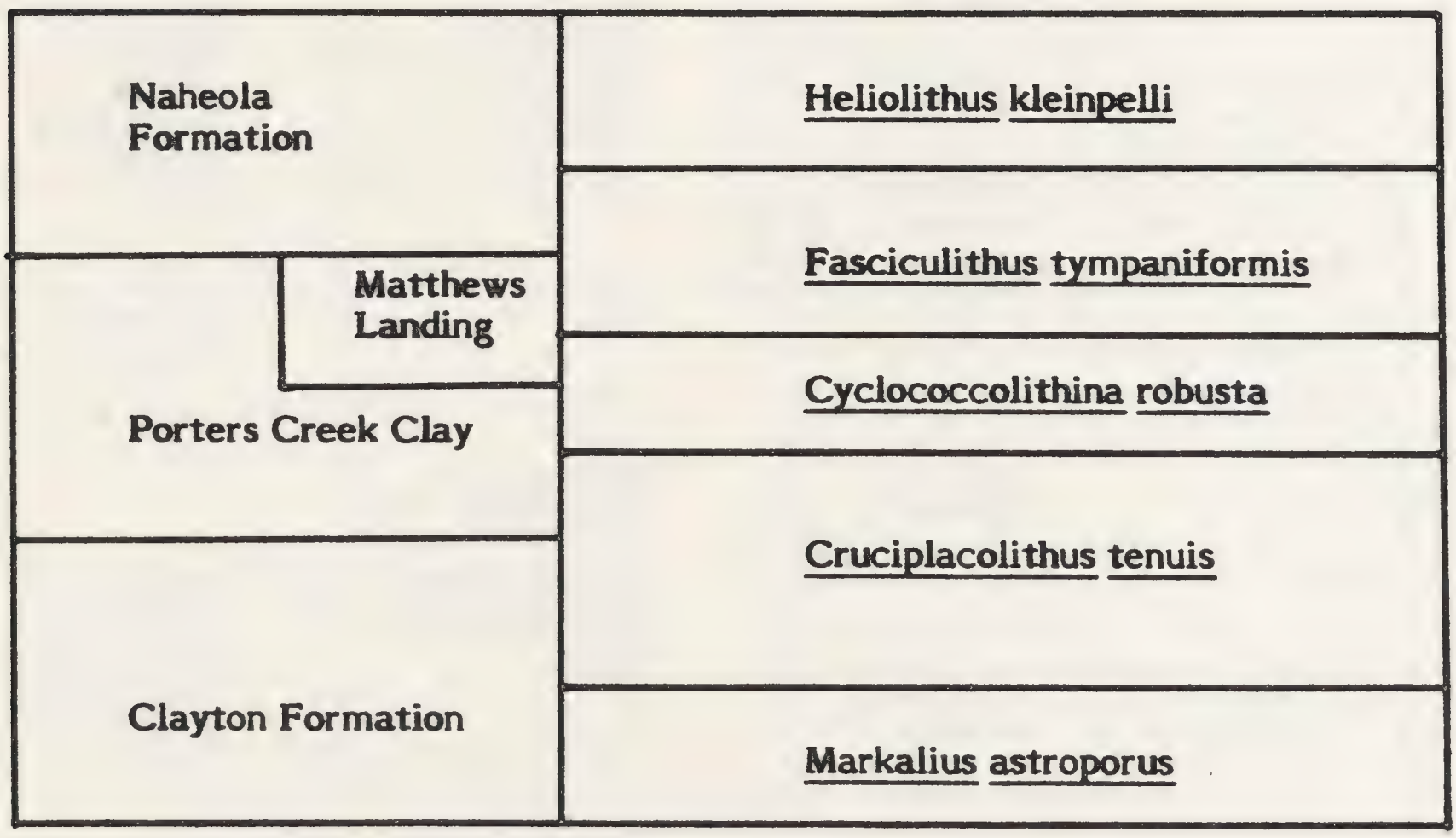

Figure 21 - Provisional Calcareous Nannoplankton zonation of the Alabama Midway based on foraminiferal zones of Blow

The samples examined are not from a single stratigraphic section, thus the primary relationship that can be determined is that of relative abundance and preservation. Sample CN-100 showed the poorest preservation with many specimens broken. Sample CN-78, from the type locality of the Midway, contained specimens in excellent condition. Species common to all three McBryde samples are:

Chiasmolithus californicus
Coccolithus cavus var. a
Coccolithus crassus var. b
Coccolithus orbiculatus
Cruciplacolithus tenuis var. b
Markalius astroporus
Neococcolithes protenus
Prinsius martinii
Thoracosphaera cf. *T. imperforata*
Zygodiscus sigmoides

The following species were common to abundant in at least two of the three McBryde Member samples:

Prinsius dimorphosus
Coccolithus cavus var. a
Thoracosphaera cf. *T. imperforata*

One noticeable point of nannofossil distribution in the McBryde Member is that *Prinsius martinii* is more abundant in sample CN-78, and that this sample does not contain *Prinsius dimorphosus*. This indicates that sample CN-78 is stratigraphically above the other two samples, as the stratigraphically higher Matthews Landing Mermber of the Porters Creek Clay also contains *Prinsius martinii* but not *Prinsius dimorphosus*.

The Porters Creek samples contained calcareous nannoplankton only in very small numbers. Only two species were present, *Cyclococcolithina robusta* and *Zygodiscus sigmoides*, both of which also occur in one sample of the Matthews Landing Member. The representatives of these species were only in fair condition, apparently due to partial solution.

The Matthews Landing Member contained 18 species of 12 genera of calcareous nannoplankton. Three species are confined to the Matthews Landing Member:

Braarudosphaera bigelowi
Cyclococcolithina cf. *C. robusta*
Discolithina versa

Four species appear in all three samples:

Prinsius martinii
Coccolithus species
Heliorthus concinnus
Thoracosphaera cf. *T. imperforata*

Only two species, *Prinsius martinii* and *Coccolithus* species, are common to abundant in two of the three samples. Sample CN-26 was more diverse in the number of species represented, but most were present only in rare numbers.

		Foraminifer Zones (Blow, 1969)	Nannofossil Zones (Gartner, 1971)
CLAYTON FORMATION	McBryde Member	Globorotalia pusilla pusilla zone P 3	Fasciculithus tympaniformis zone
	Pine Barren Member	Globorotalia uncinata zone P 2	Cruciplacolithus tenuis zone
	Pine Barren Member		Markalius astroporus zone

Figure 22 - Midway Calcareous Nannoplankton Zones after Hay and Mohler (1967)

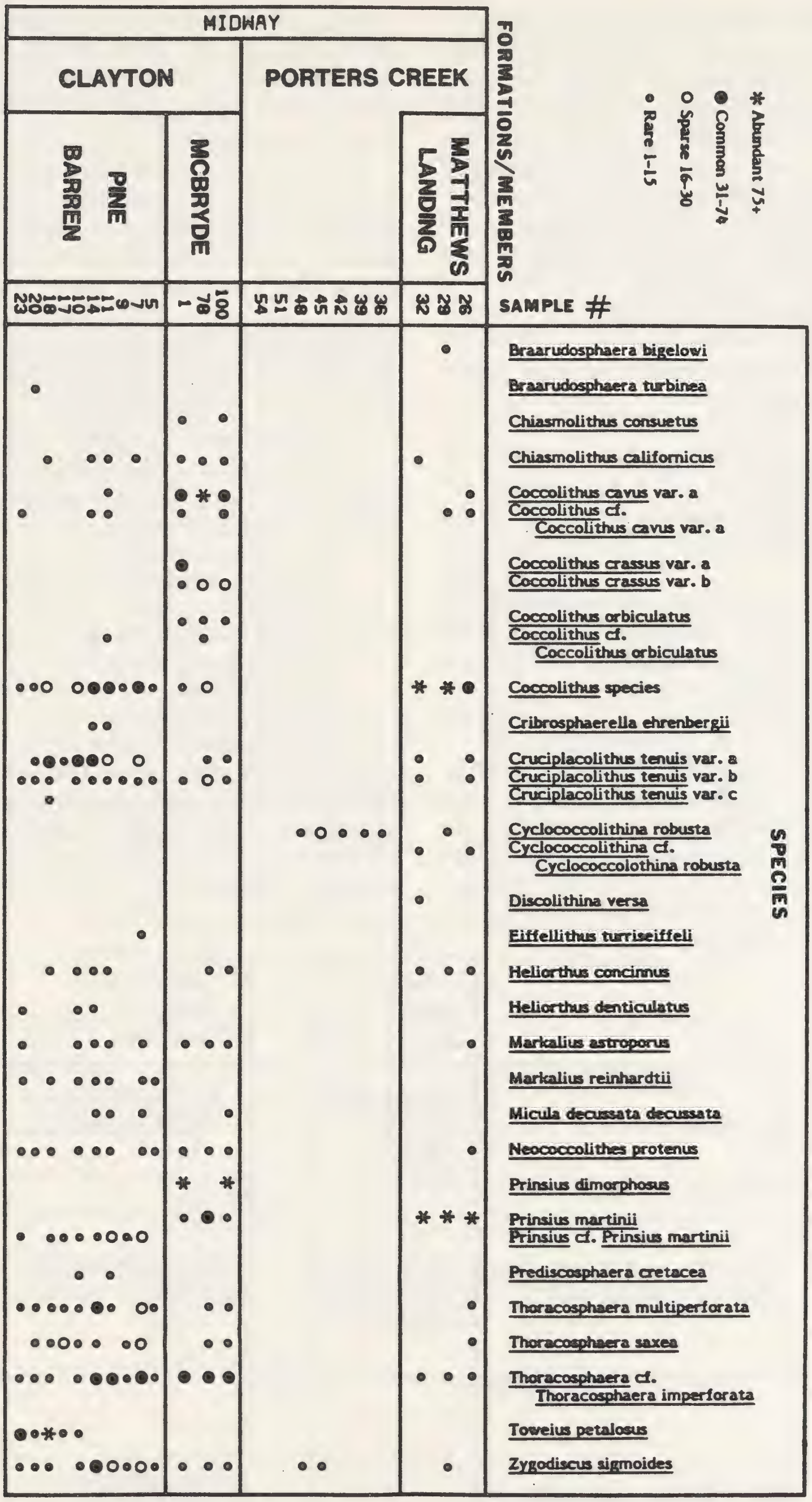

Figure 23 - Distribution and abundance of Calcareous Nannoplankton in the Alabama Midway Group. (Formations and Members not shown were barren of nannoplankton)

The samples from the Naheola Formation and the Oak Hill and Coal Bluff members of the Naheola were barren of calcareous nannoplankton. The samples from the type locality of the Clayton Formation were also barren of nannoplankton, apparently due to the recrystallization of the limestone.

The distribution and abundances of the calcareous nannoplankton are representative of the changing environmental conditions during the deposition of the Midway units. The calcareous deposits of the Clayton unit represent a shallow marine environment with an abundance of calcareous nannoplankton. The overlying Porters Creek Clay was deposited in a more open-marine environment (Bornhauser, 1947) but contains only two species of nannoplankton present in rare numbers. This indicates either that the environment was unfavorable for nannoplankton, possibly due to turbid water, or that preservation of the nannoplankton was poor as is evidenced by the poor conditions of the specimens seen in the samples. The two species present are more abundant in the Porters Creek Clay than in the Matthews Landing Member and may be indicators of the environmental conditions.

The Matthews Landing Member is calcareous and represents a more shallow-marine environment, similar to that represented by the Pine Barren and McBryde members of the Clayton Formation. This is evidenced by the fact that all three units contain some of the same species. But the environment of the Matthews Landing Member also must have been slightly different from that of the Clayton units as indicated by:

(1) The species common to the Clayton units and the Matthews Landing Member are generally present in more samples and/or greater numbers in individual samples in the two stratigraphically lower Clayton members;

(2) These two Clayton units also show a greater diversity in number of species;

(3) Some species appear and are confined to the Matthews Landing Member. This may be due to the restriction of these species to the environment present at the time of deposition of this unit, or to the evolution and extinction of certain forms.

The overlying Oak Hill and Coal Bluff members of the Naheola Formation are composed of sandy clays with lignitic, glauconitic, and micaceous layers indicative of very shallow marine or swamp conditions. Both of these units are barren of nannoplankton. The clays and sandy clays of the type locality of the Naheola Formation must have also been deposited in very shallow environments since no nannoplankton were found in the samples from this unit.

The examination of the samples from the Midway Group of Alabama results in the placement of;

(1) The Pine Barren and McBryde members of the Clayton Formation in the *Cruciplacolithus tenuis* zone of Cartner (1970), based on the presence of *Cruciplacolithus tenuis* and *Markalius astroporus* in samples from both members.

(2) The Porters Creek Clay and the Matthews Landing Member in the *Cyclococcolithina robusta* zone of Gartner (1970), based on the presence of *Cyclococcolithina robusta* in samples from both units, and on the presence of *Cruciplacolithus tenuis* and *Markalius astroporus* in the Matthews Landing samples.

Heliorthus concinnus and *Chiasmolithus consuetus*, indicators of the *Fasciculithus tympaniformis* zone, as defined by Hay *et al.* (1967), are present in the Pine Barren, McBryde, and/or Matthews Landing samples. These species are not indicators of the *Fasciculithus tympaniformis* zone in the Alabama Midway Group since they are restricted to the calcareous facies. If these two species were indicators of this zone most of the Alabama Midway section would have to be placed in the *Fasciculithus tympaniformis* zone, based only on the presence of these two species with *Fasciculithus tympaniformis* being absent. Thus the three lower Paleocene nannofossil zones would have to be contained in the lower part of the Pine Barren Member.

The absence of the key species *Fasciculithus tympaniformis* agrees with the findings of Hay and Mohler (1967), who assigned a section of the McBryde Member of the Clayton Formation to the *Fasciculithus tympaniformis* zone, but stated that this species was absent. Hay and Mohler (1967) assigned two sections of the

Pine Barren Member to the *Markalius astroporus* and *Cruciplacolithus tenuis* zones. The Pine Barren samples used in the present study are apparently from the higher stratigraphic portions of the Pine Barren section and represent only the *Cruciplacolithus tenuis* zone.

The zonation resulting from the present study of the nannoplankton in the Alabama Midway Group agrees more with the provisional nannoplankton zonation based on correlation of standard nannoplankton zones with Gulf Coast Paleocene foraminiferal zones (see figure 21), than with the Midway nannoplankton zonation of Hay and Mohler (1967).

VII. ACKNOWLEDGMENTS

The author wishes to thank Hubert C. Skinner, Harold Vokes, and Stefan Gartner for their assistance and advice during the course of this study.

VIII. SYSTEMATIC PALEONTOLOGY

The classification followed in the present study is that of the *Code of Botanical Nomenclature*.

Kingdom PLANTAE
Subkingdom PROTOBIONTA
Rothmaler, 1948
Division PHAEOPHYTA Wettstein,
emend., Rothmaler, 1949
Subdivision CHRYSOPHYTINA
Rothmaler, 1949
Class COCCOLITHOPHYCEAE
Rothmaler, 1949
Subclass COCCOLITHOPHYCIDAE
Rothmaler, 1949
Order PYRMNESIALES
Christensen, 1962
Family COCCOLITHACEAE
Kamptner, 1928
Subfamily COCCOLITHOIDEAE
Kamptner, 1928
Genus COCCOLITHUS Schwarz, 1894

Type species: Coccolithus oceanicus Schwarz, 1894

Definition: Elliptical placoliths with the distal shield larger than the proximal shield and joined to the proximal shield by a hollow tube. Both shields concave on the proximal side.

COCCOLITHUS CAVUS var. a

Plate 1, figures 1 and 2

Coccolithus cavus HAY and MOHLER, 1967, p. 1524, pl. 196, figs. 1-3; pl. 197, figs. 5, 7, 10, 12. PERCH-NEILSEN, 1969b, p. 322, pl. 33, figs. 3-6.

Ericsonia cava (HAY and MOHLER), PERCH-NIELSEN, 1969a, p. 61, pl. 4, figs. 13, 14.

Description: This large elliptical placolith has a distal shield composed of approximately 48 elements which show a slight dextral imbrication. The central area forms a depression that is partially filled by a cycle of elongate trapezoidal elements. The small central opening makes up approximately one-fifth of the total width of the placolith. The proximal shield is composed of the same number of elements as the distal shield but has a serrate margin.

Size: Maximum length 10 microns.

Occurrence: This species was reported from the Paleocene of France and Austria and was found in the Pine Barren and

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PLATE 1

Figures 1, 2. *Coccolithus cavus* var. a; Sample CN-78
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
2. Electron micrograph, x9500, distal view
Figure 3. *Coccolithus* cf. *C. cavus* var. a; Sample CN-26
3a. Cross-polarized light, x3250, 70° to polarizer
3b. Transmitted light, x3250
3c. Phase-contrast, x3250
Figure 4. *Coccolithus* species; Sample CN-5
4a. Cross-polarized light, x3250, 70° to polarizer
4b. Transmitted light, x3250

*The cross-polarized light photographs were taken with the long axes of the specimen parallel to the polarizer unless stated otherwise.

1a

1b

2

3a

3b

3c

4a

4b

PLATE 1

McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

COCCOLITHUS cf. COCCOLITHUS CAVUS var. a
Plate 1, figure 3

Description: The distal shield of this large elliptical placolith is composed of approximately 50 elements surrounding an indistinct central area. No central opening can be seen.

Discussion: Specimens included here are similar but not identical to *Coccolithus cavus* var. a. These forms have the same general size and structure of *Coccolithus cavus* var. a but have an indistinct central area.

Size: Maximum length 10 microns.

Occurrence: Representatives of this species were found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

COCCOLITHUS CRASSUS var. a
Plate 2, figure 1

Description: This elliptical placolith has a distal shield composed of approximately 60 elements which meet along straight sutures. The large central area contains a thick collar and a wide central opening. The central opening makes up approximately one-third of the total width of the placolith.

Size: Maximum length 8 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

COCCOLITHUS CRASSUS var. b
Plate 2, figure 2

Coccolithus crassus BRAMLETTE and SULLIVAN, 1961, p. 139, pl. 1, figs. 4a-d.

Description: The distal shield of this elliptical placolith is composed of approximately 60 elements which meet along straight sutures. The large central area is partially closed by the apparently flat wide collar that surrounds the central opening. The central opening makes up approximately one-fourth of the total width of the placolith.

Discussion: This species differs from *Coccolithus crassus* var. a in being slightly more elliptical, having a slightly smaller central opening, and having an apparently flatter collar.

Size: Maximum length 8 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

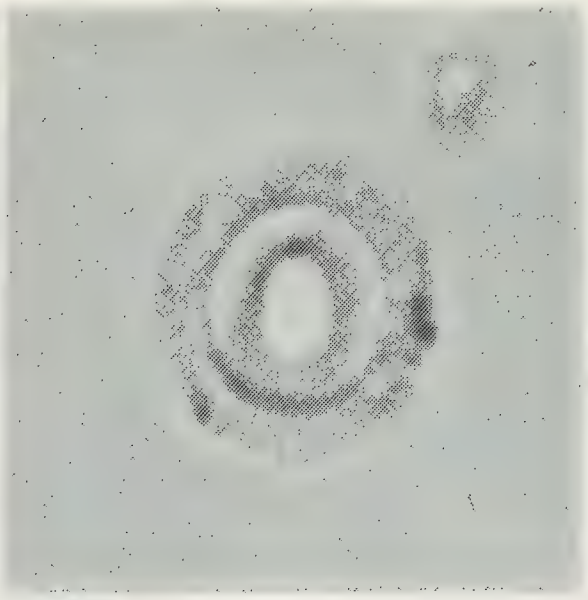
COCCOLITHUS ORBICULATUS n. sp.
Plate 8, figure 5

Description: This circular placolith has approximately 45 elements in the distal field. The large central area has a small central opening, which makes up approximately one-sixth of the total width of the placolith.

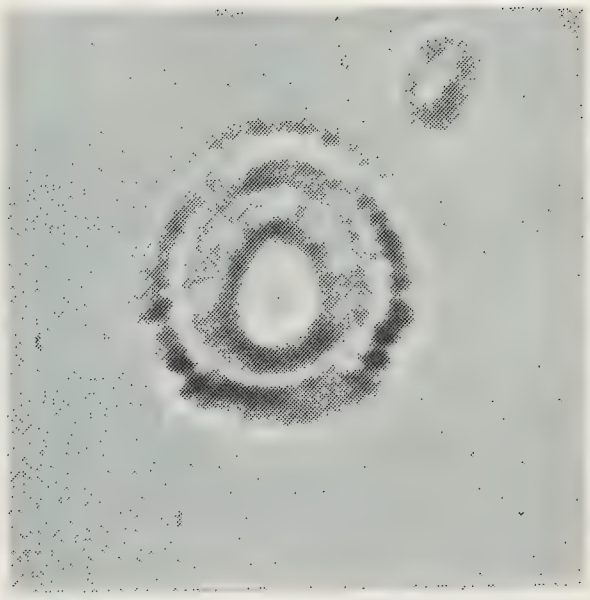
PLATE 2

Figure 1. *Cocclithus crassus* var. a; Sample CN-1
1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
1c. Interference-contrast, x3250
Figure 2. *Coccolithus crassus* var. b; Sample CN-1
2a. Cross-polarized light, x3250
2b. Transmitted light, x3250
2c. Oblique illumination, x3250
Figure 3. *Discolithina versa* (Bramlette and Sullivan), n. comb.; Sample CN-32
3a. Cross-polarized light, x3250, 90° to polarizer
3b. Cross-polarized light, x3250, 45° to polarizer
3c. Transmitted light, x3250
Figure 4. *Braarudosphaera bigelowii* (Gran and Braarud) Deflandre; Sample CN-29
4a. Cross-polarized light, x3250
4b. Transmitted light, x3250
4c. Phase-contrast, x3250

1a

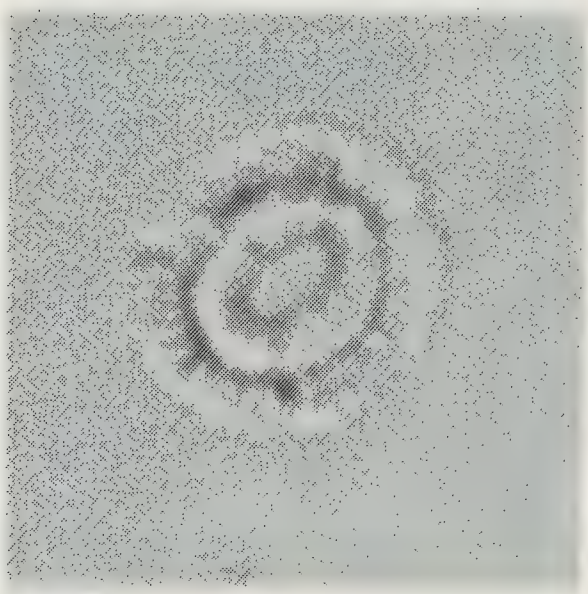


1b

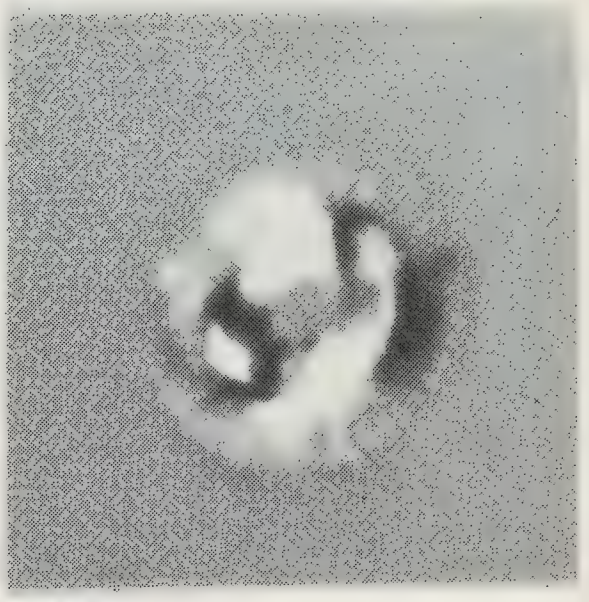


1c

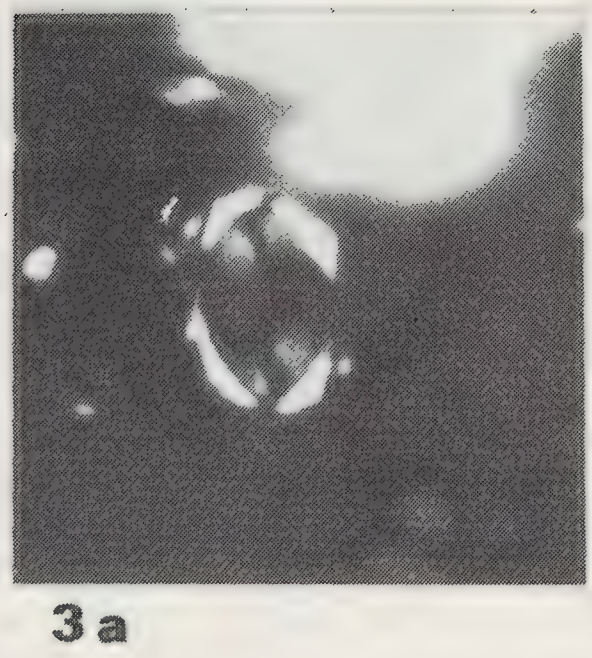
2a



2b

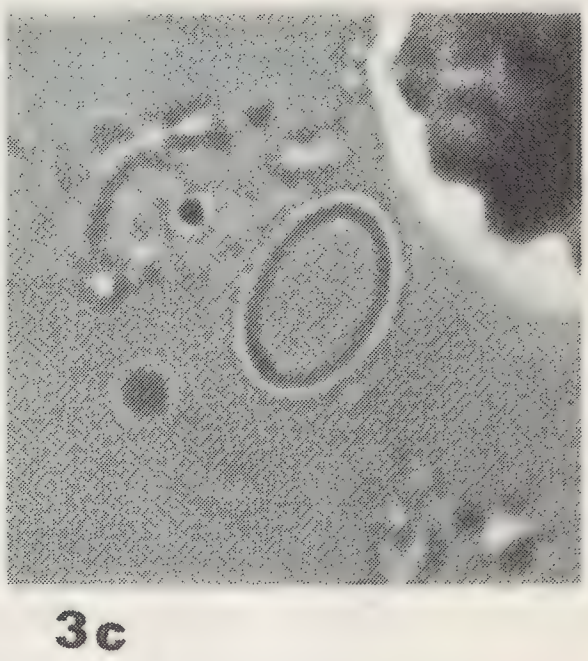


2c



3a

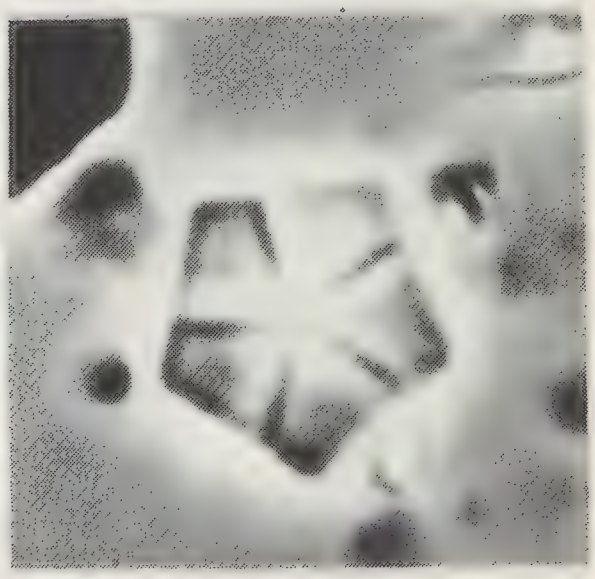
3b



3c

4a

4b



4c

PLATE 2

Discussion: This species differs from forms of *Coccolithus cavus* in being circular. It differs from certain species of *Markalius* in that the central area is open.

Size: Maximum diameter 6 microns.

Occurrence: Representative of this species were found in the McBryde Member of the Clayton Formation.

Holotype: USNM 388226-CN-1-19 (11.2 x 1.6) (Plate 8, figure 5).

COCCOLITHUS cf. COCCOLITHUS ORBICULATUS
Plate 8, figure 6

Discussion: This group includes forms that are identical to *Coccolithus orbiculatus* except for being slightly larger and showing a slight dextral imbrication of the elements of the distal shield.

Size: Maximum diameter 6 microns.

Occurrence: This form was found in the McBryde Member of the Clayton Formation.

COCCOLITHUS species
Plate 1, figure 4; Plate 13, figure 1

Description: These elliptical placoliths have distal shields of approximately 30-60 elements. The size of the central area varies. The interference pattern consists of a dark rim with a dark cross in the central area, which separates into two V-shaped lines when rotated 45 degrees.

Discussion: Included here are two different coccolith species not assignable to others noted, which showed a high variability and occurred only in very low numbers.

Size: Maximum length 8 microns.

Occurrence: These forms were found in the Matthews Landing Member of the Porters Creek Clay, and in the Pine Barren and McBryde members of the Clayton Formation.

Genus CHIASMOLITHUS Hay, Mohler, and Wade, 1966

Type species: Chiasmolithus oamaruensis (Deflandre) Hay, Mohler, and Wade, 1966.

Description: Placoliths with a large central opening spanned by an X-shaped structure. The distal rim is larger than the proximal rim.

CHIASMOLITHUS CALIFORNICUS
(Sullivan) Hay and Mohler
Plate 5, figure 3

Coccolithus aff. *C. gigas* BRAMLETTE and SULLIVAN, 1961, p. 140, pl. 1, fig. 7 a-d.

Coccolithus californicus SULLIVAN, 1964, p. 180, pl. 2, figs. 3 a, b; 4 a-b; SULLIVAN, 1965, p. 31.

Chiasmolithus californicus (Sullivan). HAY and MOHLER, 1967, p. 1527, pl. 196, figs. 18-20; pl. 198, fig. 5.

Description: This elliptical placolith has a distal shield composed of approximately 60 elements, which show a slight dextral imbrication. The large central area is spanned by an X-shaped structure. Both of the bars of the X have a sigmoid shape, one bar being longer than the other. The X is

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PLATE 3

Figure 1. *Cyclococcolithina robusta* (Bramlette and Sullivan) Gartner; Sample CN-39
- 1a. Cross-polarized light, x3250
- 1b. Transmitted light, x3250
- 1c. Interference-contrast, x3250

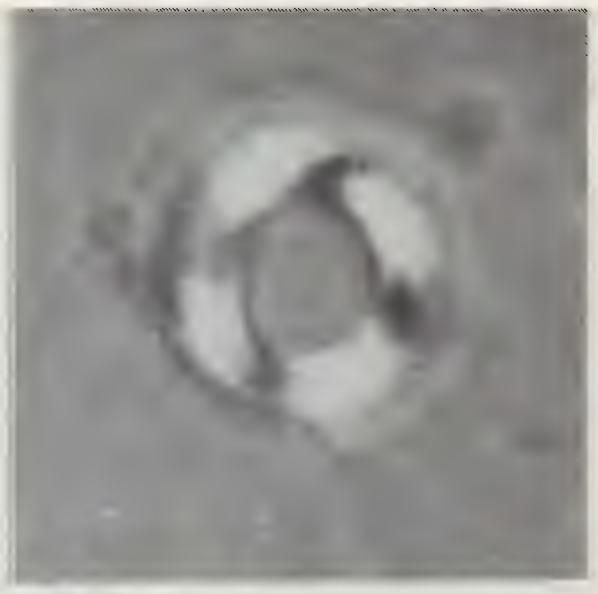
Figure 2. *Cyclococcolithina* cf. *C. robusta*; Sample CN-26
- 2a. Cross-polarized light, x3250
- 2b. Phase-contrast, x3250

Figures 3, 4. *Prinsius* cf. *P. martinii*; Sample CN-11
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250
- 4a. Cross-polarized light, x3250
- 4b. Phase-contrast, x3250

Figure 5. *Braarudosphaera turbinea* Stradner; Sample CN-20
- 5a. Cross-polarized light, x3250
- 5b. Transmitted light, x3250
- 5c. Phase-contrast, x3250

1a

1b



1c

2a

2b

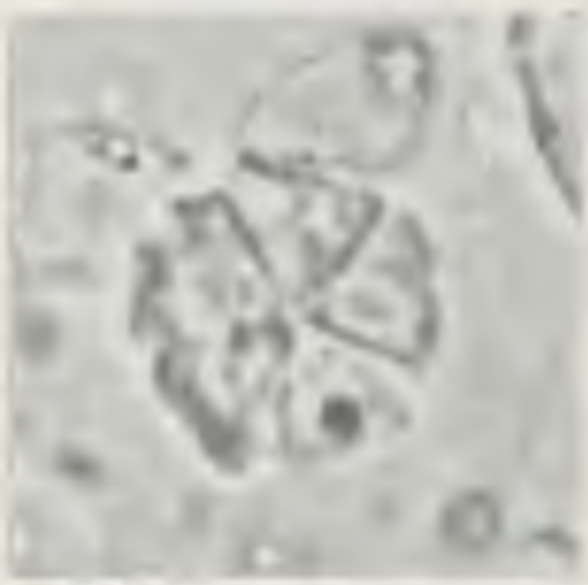
3a

4a

4b

3b

5a



5b

5c

PLATE 3

offset slightly to the major and minor axis of the ellipse.

Discussion: The species differs from *Chiasmolithus consuetus* in being large and having more elements in the distal shield. The bars of the central X-shaped structure are sigmoidally shaped in both species but are more nearly aligned with the equal axis of the ellipse in *Chiasmolithus consuetus*.

Size: Maximum length 9 microns.

Occurrence: This species was originally described from the Lodo Formation of California and at Pont Labau in France, and was found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

CHIASMOLITHUS CONSUETUS
(Bramlette and Sullivan) Hay and Mohler
Plate 5, figures 1 and 2

Coccolithus consuetus BRAMLETTE and SULLIVAN, 1961, p. 139, pl. 1, figs. 2 a-c. STRADNER *in* GOHRBANDT, 1963, p. 74, pl. 8, figs. 10-12. SULLIVAN, 1964, p. 180, pl. 3, figs. 1 a-b; SULLIVAN, 1965, p. 31.

Chiasmolithus consuetus (Bramlette and Sullivan). HAY and MOHLER, 1967, p. 1526, pl. 196, figs. 23-25; pl. 198, fig. 16.

Description: This regularly elliptical placolith has a distal shield composed of approximately 60 slightly trapezoidal elements, which show a slight dextral imbrication. The central opening is spanned by an X-shaped cross bar more or less aligned with the axes of the ellipse. This central structure is composed of overlapping rhombs of calcite. Each of the bars of the X curve slightly in opposite directions giving each bar a sigmoid shape.

Discussion: The specimens seen in the Midway samples differ from previously described forms in having more elements in the distal shield.

Size: Maximum length 11 microns.

Occurrence: This species was reported from the Lodo Formation of California and from Pont Labau in France and occurs in the McBryde Member of the Clayton Formation.

Genus CRUCIPLACOLITHUS Hay and Mohler, 1967

Type species: *Cruciplacolithus tenuis* (Stradner) Hay and Mohler, 1967

Definition: Elliptical placolith with both shields being concave on the proximal side. The open central area is spanned by a central cross whose bars are aligned with the major and minor axes of the coccolith.

CRUCIPLACOLITHUS TENUIS var. a
Plate 11, figure 4

Description: The distal shield of this elliptical placolith is composed of approximately 45 elements and has a central depression with a sloping margin. The very large central opening is spanned by a thin cross, which is aligned with the major and minor axes of the ellipse. The central opening makes up approximately two-thirds of the total width of the placolith.

Discussion: This form differs from *Cruciplacolithus tenuis* var. b in having a larger central opening and a narrower rim, and differs from var. c in having a larger central opening and a thinner collar.

Size: Maximum length 7 microns.

Occurrence: This form was found in the Pine Barren and McBryde members of the Clayton Formation and the Matthews Landing Member of the Porters Creek Clay.

CRUCIPLACOLITHUS TENUIS var. b
Plate 11, figures 1 and 2

Heliorthus tenuis STRADNER, 1961, p. 84, text figs. 64, 65.

PLATE 4

Figures 1-3. *Markalius astroporus* (Stradner) Hay and Mohler; Sample CN-78

1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
1c. Interference-contrast, x3250
2a. Electron micrograph, x4800, proximal view
2b. Electron micrograph, x19,100, proximal view
3. Oblique illumination, x3250

1a

1b

1c

3

2a

2b

PLATE 4

Coccolithus helis STRADNER *in* GOHRBANDT, 1963, p. 74, pl. 8, fig. 16; pl. 9, figs. 1, 2. BRAMLETTE and MARTINI, 1964, p. 298-299, pl. 1, figs. 10-12; *non* pl. 7, figs. 5 a, b, 6.

Cruciplacolithus tenuis (Stradner). HAY and MOHLER, 1967, p. 1527, pl. 198, figs. 1, 17; *non* pl. 196, figs. 29-31. PERCH-NIELSEN, 1969a, p. 59, pl. 1, figs. 7, 8; PERCH-NIELSEN, 1969b, p. 323, pl. 34, figs. 1-7.

Description: This elliptical placolith has a distal shield composed of a broad rim of approximately 40 to 55 elements, and has a central depression with a sloping margin. The moderate-sized central opening may be almost entirely closed by the broad cross-shaped central structure that spans the central opening. The cross is aligned with the major and minor axes of the ellipse. Scanning electron micrographs show the bars of the cross to be composed of two rows of flat rhombs that overlap. The central depression may be covered by a cycle of small short elements.

Discussion: This variety of *Cruciplacolithus tenuis* is larger than variety a and has a broader rim and a much smaller central opening. *Cruciplacolithus tenuis* var. c is smaller and has a thinner collar and a larger central opening than this variety.

Size: Maximum length 10 microns.

Occurrence: This form was found in the Pine Barren and McBryde members of the Clayton Formation and in the Matthews Landing Member of the Porters Creek Clay.

CRUCIPLACOLITHUS TENUIS var. c
Plate 11, figure 3

Description: The distal shield of this elliptical placolith is composed of approximately 55 elements. The broad rim surrounds a central area with a thin collar and a large central opening. The central opening is spanned by a thin cross, which is aligned with the major and minor axes of the ellipse.

Discussion: This form differs from *Cruciplacolithus tenuis* var. a in having a broader rim, a thicker collar, and a smaller central opening; and from *Cruciplacolithus tenuis* var. b in being slightly smaller, having a more open central area, and having a thinner collar.

Size: Maximum length 8 microns.

Occurrence: This form was found in the Pine Barren Member of the Clayton Formation.

Subfamily CYCLOCCOLITHOIDEAE
Hay and Mohler, 1967

Genus CYCLOCOCCOLITHINA
(Kamptner) Wilcoxon, 1970

Type species: *Cyclococcolithina leptopora* (Murray and Blackman) Wilcoxon, 1970.

Definition: Circular placoliths having a circular central perforation.

CYCLOCOCCOLITHINA ROBUSTA
(Bramlette and Sullivan) Gartner
Plate 3, figure 1

Cyclolithus? robustus BRAMLETTE and SULLIVAN, 1961, p. 141, pl. 2, figs. 7 a-c.

Cyclococcolithina robusta (Bramlette and Sullivan). GARTNER, 1967, p. 104.

Description: This circular placolith has a large central opening with approximately 55 elements in both the distal and proximal shields. The distal shield is larger than the proximal shield. The large central opening is bordered by a narrower collar.

Discussion: The forms examined in the present study have two shields of elements forming a placolith instead of a single grooved ring as reported by Bramlette and Sullivan. No electron micrographs were taken of this species so the actual structure

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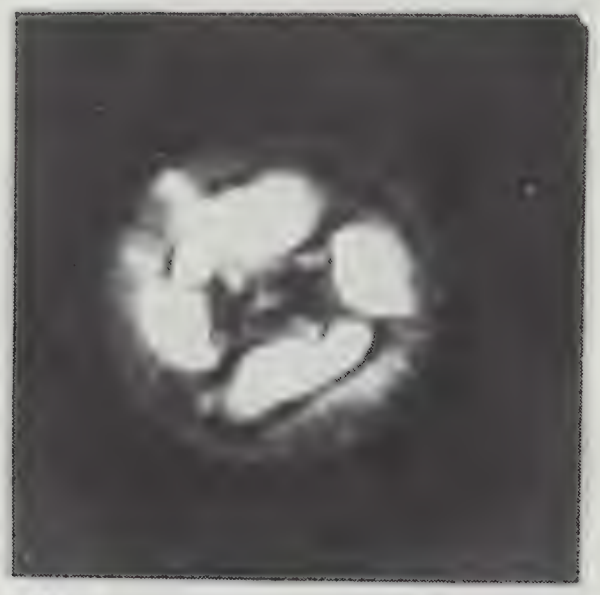
PLATE 5

Figures 1, 2. *Chiasmolithus consuetus* (Bramlette and Sullivan) Hay and Mohler; Sample CN-1

1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
2. Electron micrograph, x4800, distal view

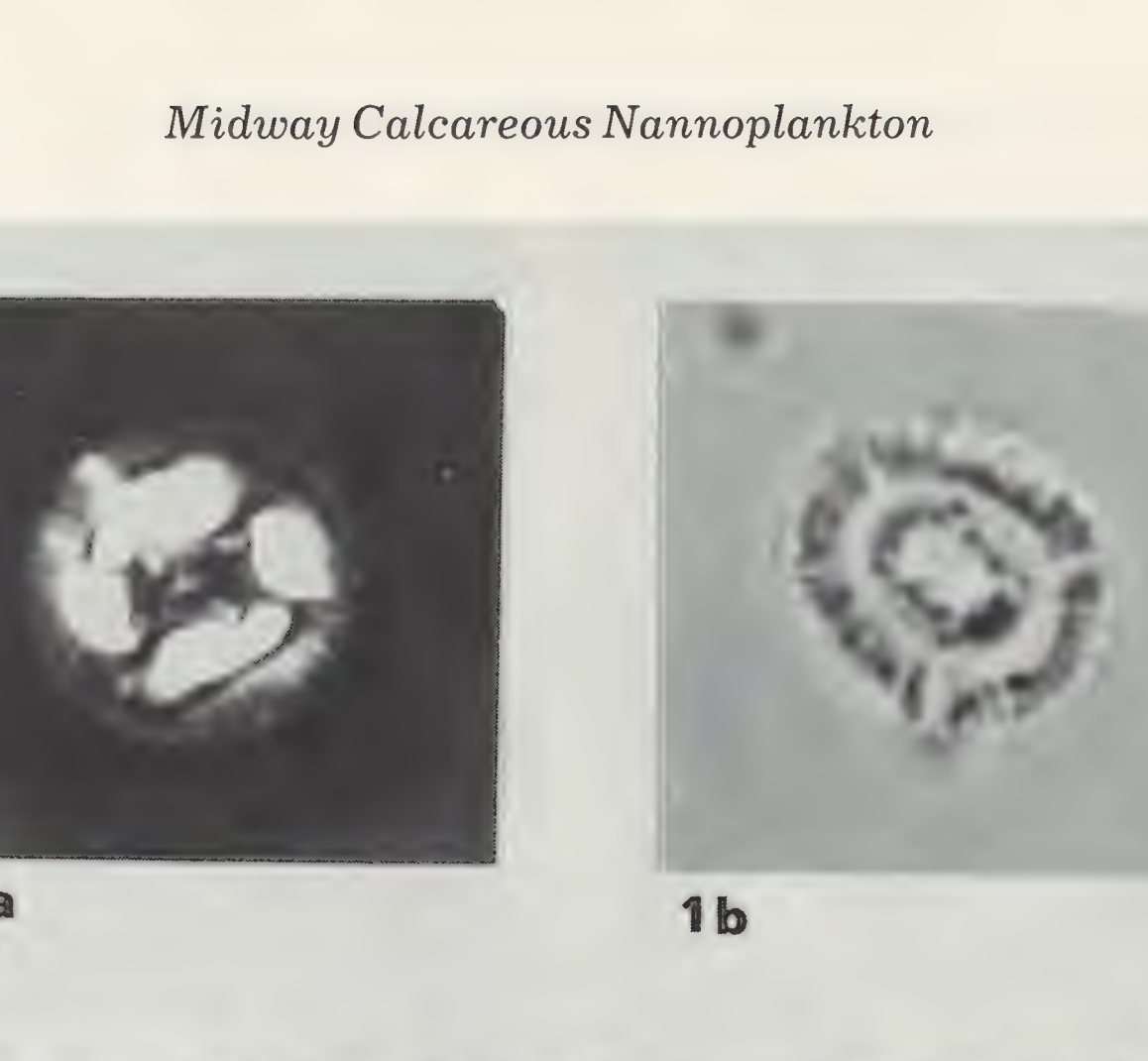
Figure 3. *Chiasmolithus californicus* (Sullivan) Hay and Mohler; Sample CN-1

3a. Cross-polarized light, x3250
3b. Transmitted light, x3250



1a

1b



2

3a

3b

PLATE 5

of these forms is not known. All of the specimens of this species seen in the Alabama Midway samples appear to have been partially dissolved.

Size: Maximum diameter 9 microns.

Occurrence: This species was reported from the Paleocene of California and in samples from the Blake Plateau, and was found in the Porters Creek Clay and the Matthews Landing Member of the Porters Creek.

CYCLOCOCCOLITHINA cf. CYCLOCOCCOLITHINA ROBUSTA
Plate 3, figure 2

Description: This circular placolith has approximately 40 elements and a very large central opening.

Discussion: These forms seem to be the inner portion of specimens of *Cyclococcolithina robusta*, which have undergone partial solution. The size, and shape is similar to *Cyclococcolithina robusta*. They occur stratigraphically higher than the level of common *Cyclococcolithina robusta* and may represent reworked forms of the latter.

Size: Maximum diameter 6 microns.

Occurrence: This form was found in the Matthews Landing Member of the Porters Creek Clay.

Genus MARKALIUS
Bramlette and Martini, 1964

Type species: *Markalius inversus* (Deflandre) Bramlette and Martini, 1964

Definition: Circular placolith composed of two closely appressed shields connected by a hollow tube. The distal shield is larger and shows counterclockwise curved sutures. The interference pattern shows a dark cross in the central area with the rim being black.

MARKALIUS ASTROPORUS (Stradner) Hay and Mohler
Plate 4, figures 1-3

Cycloccocolithus astroporus STRADNER *in* GOHRBANDT, 1963, p. 75, pl. 9, figs. 5-7; text figs. 3-2 a, b.

Markalius inversus (Deflandre). BRAMLETTE and MARTINI, 1964, p. 302, pl. 2, figs. 4-9; *non* pl. 8, figs. 2 a-b. MARTINI, 1964, p. 49, pl. 6, figs. 9, 10. PERCH-NIELSEN, 1968, p. 72, pl. 24, figs. 1-8; pl. 25, fig. 1; text fig. 35; PERCH-NIELSEN, 1969a, p. 326; text fig. 5; PERCH-NIELSEN, 1969b, p. 63, pl. 3, figs. 5-6.

Markalius astroporus (Stradner). HAY and MOHLER, 1967, p. 1528, pl. 196, figs. 32-35; pl. 198, figs. 2, 6. GARTNER, 1967, p. 110.

Description: This circular placolith has a distal shield larger than the proximal shield showing a slight sinistral imbrication of the elements. Both shields are composed of 32 to 36 elements. In the scanning electron microscope the proximal shield shows a four-rayed primary structure plus auxiliary elements in the central area surrounded by a thin cycle of counterclockwise curving elements.

Size: Maximum diameter 9 microns.

Occurrence: This species has been reported from Cretaceous and Paleocene localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and in the Matthews Landing Member of the Porters Creek Clay.

MARKALIUS REINHARDTII Perch-Nielsen
Plate 10, figure 5

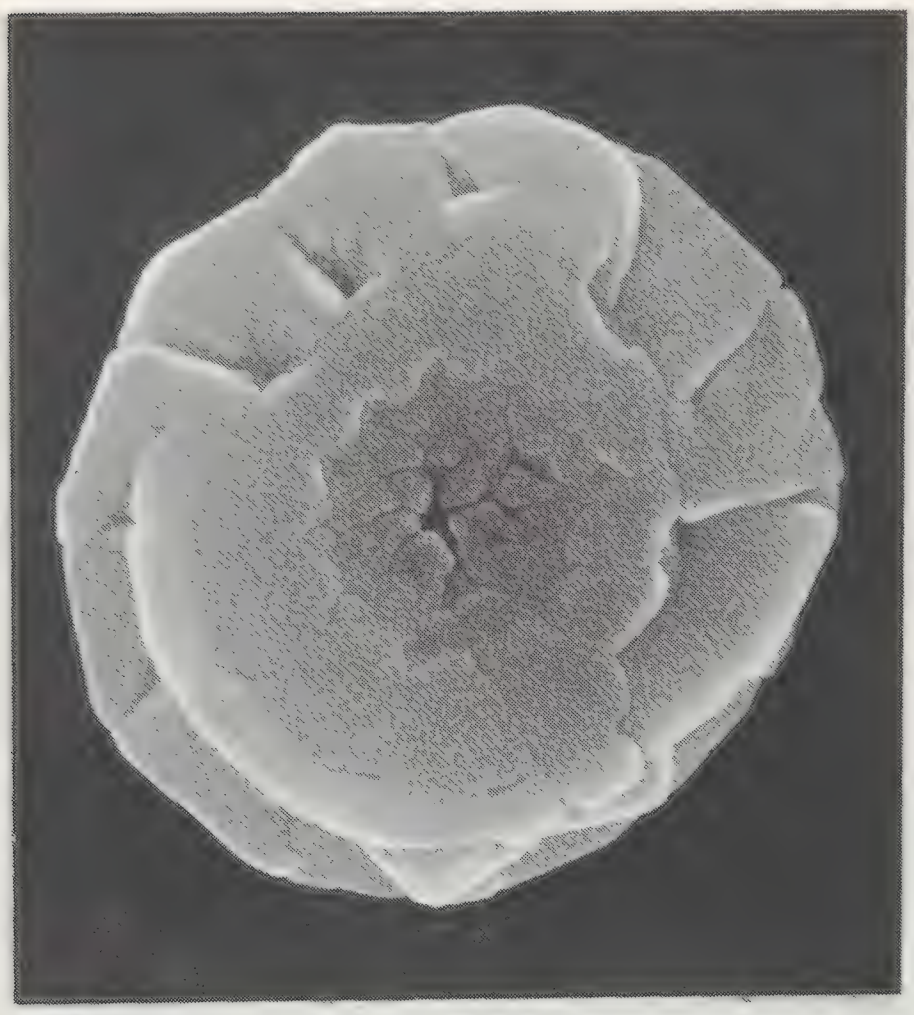
Tergestiella barnesae part (Black). REINHARDT, 1966, pl. 1, figs. 1-2; text fig. 2.

PLATE 6

Figures 1-3. *Prinsius dimorphosus* Perch-Nielsen
1. Electron micrograph, x20,300, Sample CN-100
2. Electron micrograph, x30,400, Sample CN-100
3a. Cross-polarized light, x3250; Sample CN-1
3b. Transmitted light, x3250; Sample CN-1
3c. Phase-contrast, x3250; Sample CN-1

Figure 4. *Toweius petalosus* Ellis and Lohman
4a. Cross-polarized light, x4050; Sample CN-10
4b. Phase-contrast, x4050; Sample CN-10

Figure 5. *Prinsius* cf. *P. martini*; Sample CN-7
Electron micrograph, x18,300



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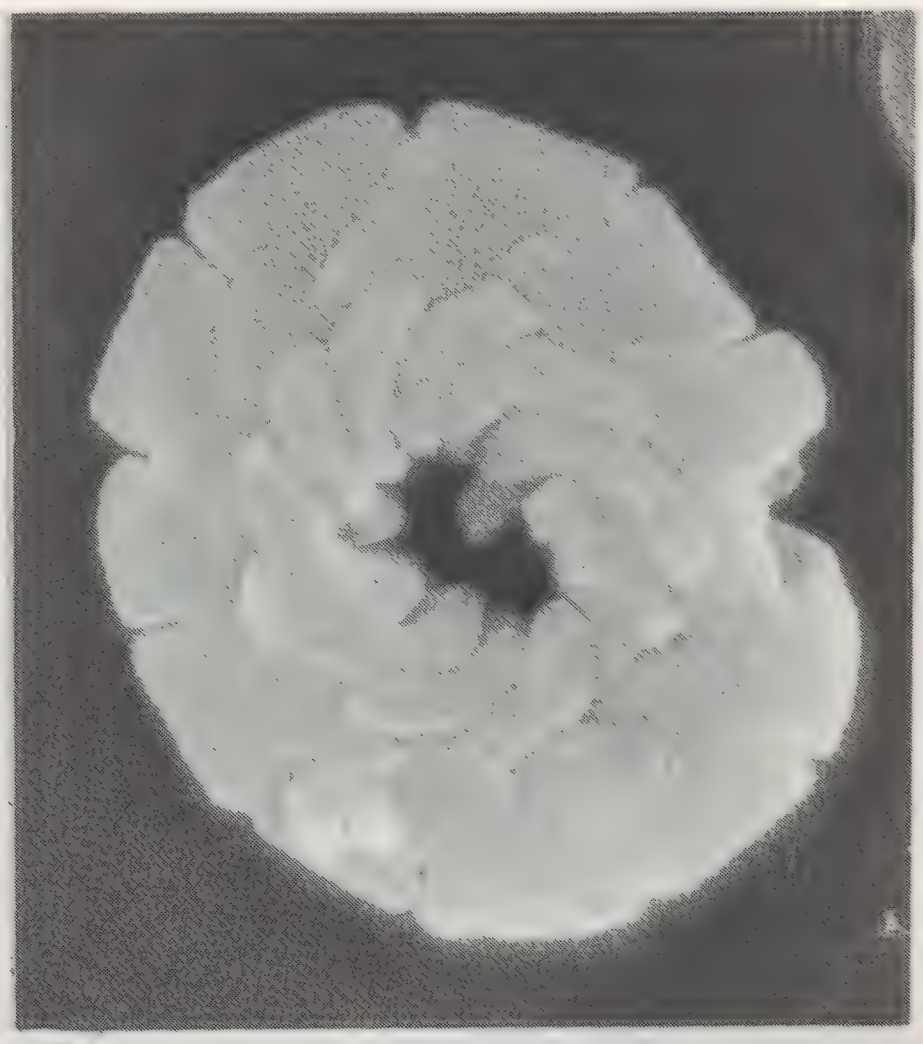

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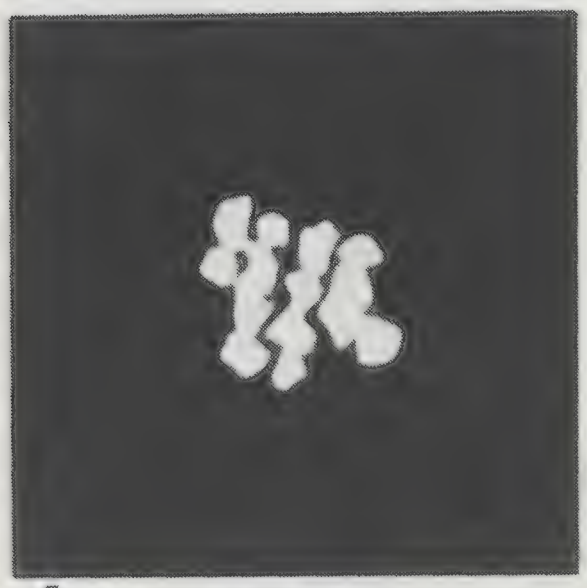
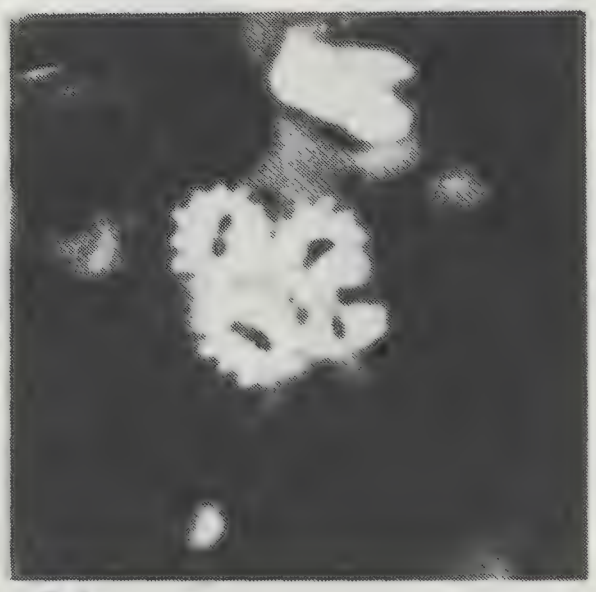
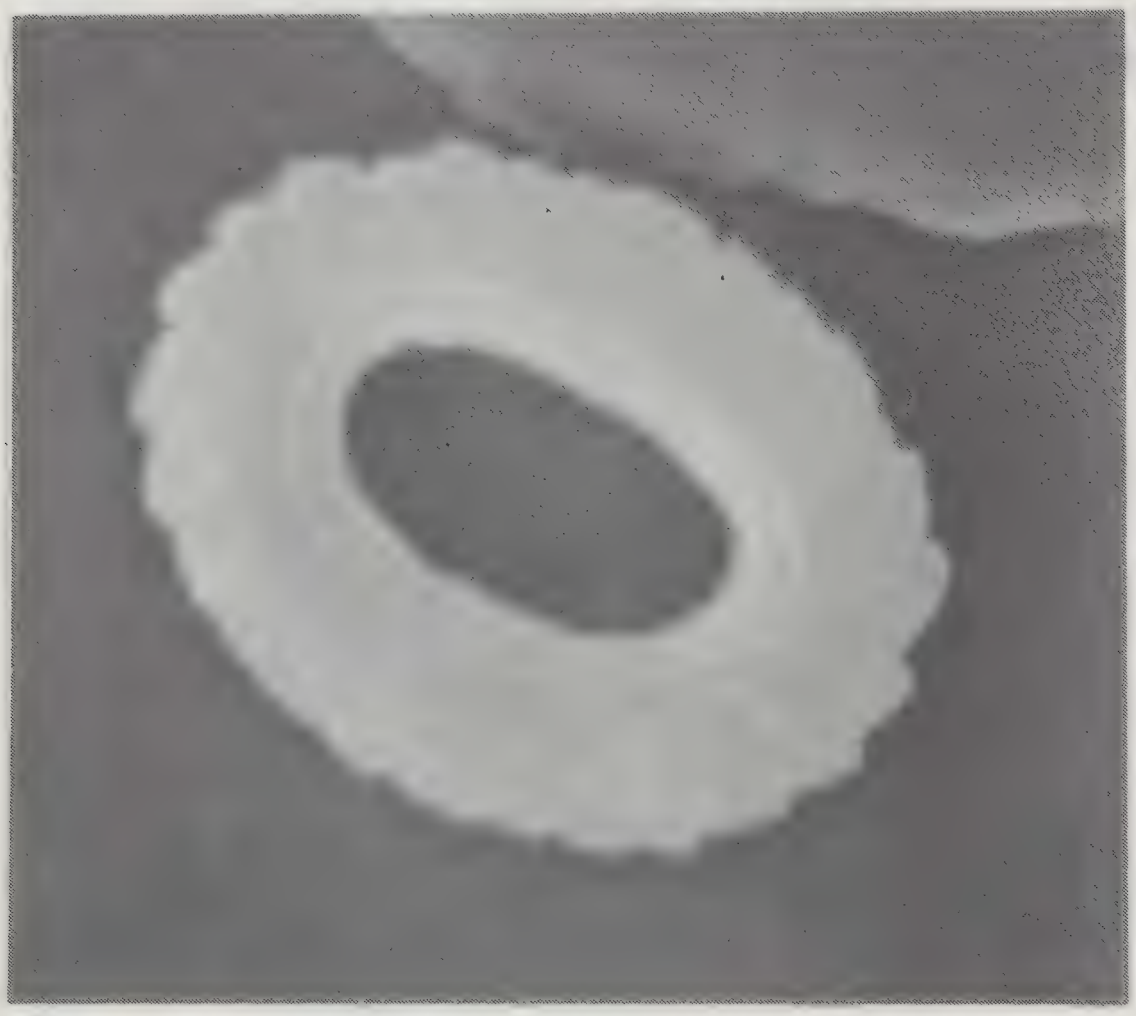


4a



4b

3a



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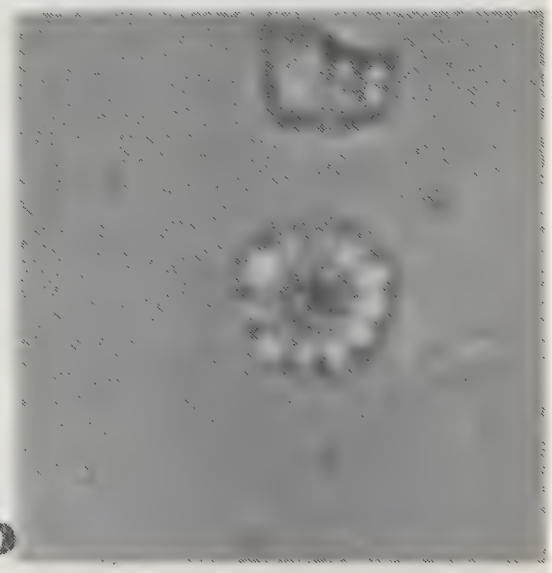


3b

3c

PLATE 6

Markalius reinhardtii PERCH-NIELSEN, 1968, p. 76, pl. 23, figs. 6-8, text figs. 34c, 38; PERCH-NIELSEN, 1969a, p. 63-64, pl. 3, figs. 2-4; pl. 7, figs. 13, 14; PERCH-NIELSEN, 1969b, p. 327, pl. 34, fig. 8.

Description: This circular placolith has a strongly sloping distal shield composed of approximately 40 overlapping elements. The overlapping edge of the elements is inclined counterclockwise near the center, changing direction near the middle of the rim and extending to the outer edge. The wide central area contains two sets of elements. The outer set consists of straight elements, which are inclined at the same angle as the elements of the outer rim. The inner set of central elements consists of at least three elements making a tall stem-like structure. Reinhardt's illustrations show this structure to have three sides.

Discussion: The forms seen in the Midway samples show a distinctive interference pattern consisting of two dark crosses, one on the outer rim and one in the center. The raised central structure is very distinctive in the light microscope.

Size: Maximum diameter 5 microns.

Occurrence: This species was reported from the Maastrichtian and Danian of Denmark and was found in the Pine Barren Member of the Clayton Formation.

Family ZYGODISCACEAE
Hay and Mohler, 1967
Genus HELIORTHUS
Bronnimann and Stradner, 1960

Type species: Heliorthus fallax Bronniman and Stradner, 1960

Definition: An elliptical ring with an X-shaped structure spanning the central opening.

HELIORTHUS CONCINNUS (Martin)
Hay and Mohler
Plate 12, figures 3 and 4

Zygolithus concinnus MARTINI, 1961, p. 18, pl. 3, fig.35; pl. 5, fig. 54. BRAMLETTE and MARTINI, 1964, p. 304, pl. 4, figs. 13, 14; *non* pl. 7, figs. 3 a, b. SULLIVAN, 1965, p. 38.

Zygolithus chiastus BRAMLETTE and SULLIVAN, 1961, p. 149, pl. 6, figs. 1 a-d; 2 a, b; 3 a, b. STRADNER *in* GOHRBANDT, 1963, pl. 10, figs. 1-3. SULLIVAN, 1964, p. 187, pl. 7, fig. 12.

Heliorthus concinnus (Martin). HAY and MOHLER, 1967, p. 1533, pl. 199, figs. 16-18; pl. 201, figs. 6, 7, 10. PERCH-NIELSEN, 1969a, p. 62, pl. 5, figs. 6-8.

Description: This elliptical coccolith has a distal rim of stongly imbricate triangular elements surrounding an inner cycle of broader triangular elements that show no imbrication. The open central area is spanned by an X-shaped structure that is formed of elongate laths. One of the bars of the structure is offset so that it does not form a straight bar. The amount of the offset varies as is shown in the figures of Bramlette and Sullivan (1961).

Discussion: The offset bar and thicker rim of this form distinguishes it from *Neococcolithes protenus*. The laths of the central structure are wider than those of *N. protenus*. Martini's (1961) original figure shows the offset nature of the central structure and makes this a distinctive feature to be used in the identification of this species.

Size: Maximum length 7 microns.

Occurrence: This species was reported from Paleocene strata in various parts of the world and was found in the samples from the Pine Barren Member and the McBryde Member of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

HELIORTHUS DENTICULATUS Perch-Nielsen
Plate 13, figures 2-5

Heliorthus denticulatus PERCH-NIELSEN, 1969a, p. 62, pl. 5, fig 5.

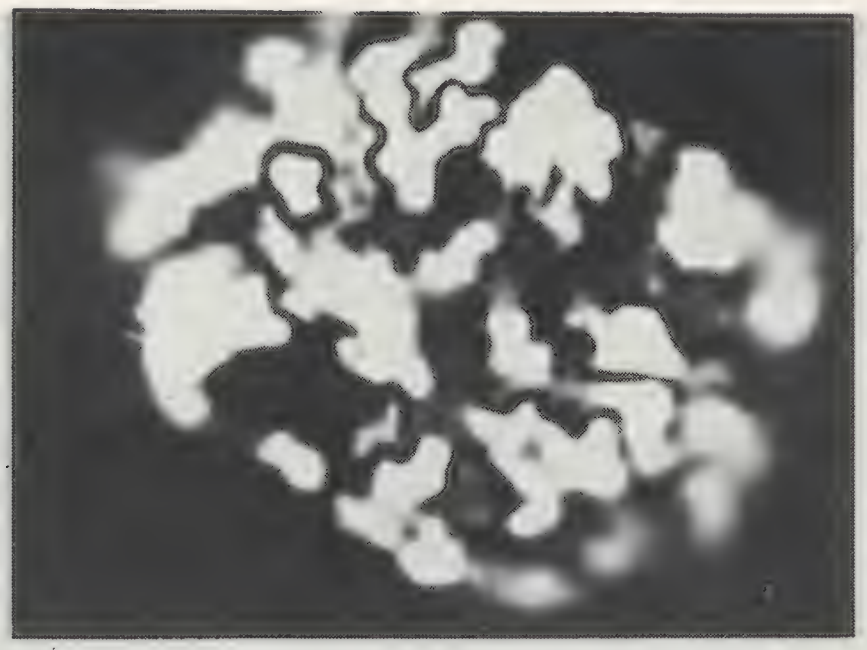
PLATE 7

Figure 1. *Thoracosphaera* cf. *T. imperforata* Kamptner; Sample CN-14, Cross-polarized light, x3250

Figure 2. *Thoracosphaera saxea* Stradner; Sample CN-18, Cross-polarized light, x3250

Figures 3-5. *Thoracosphaera multiperforata* n. sp.

3. Cross-polarized light, x3250; Sample CN-7
4. Cross-polarized light, x3250; Sample CN-14
5. Electron micrograph, x9300; Sample CN-7



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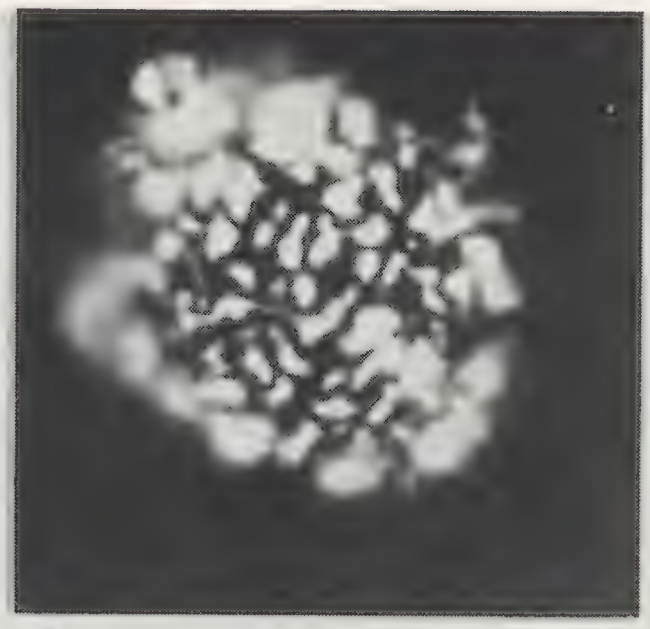

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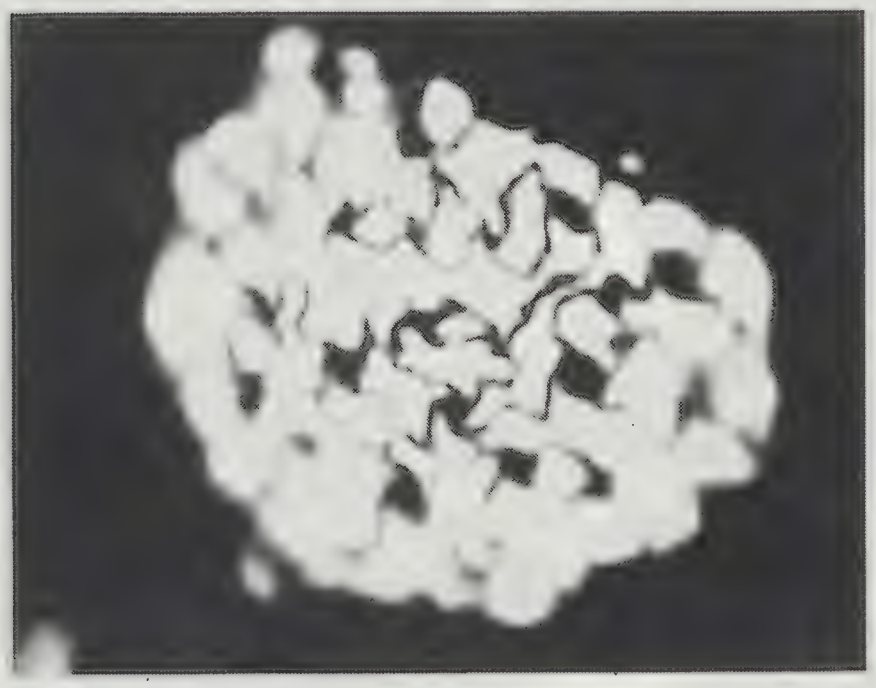

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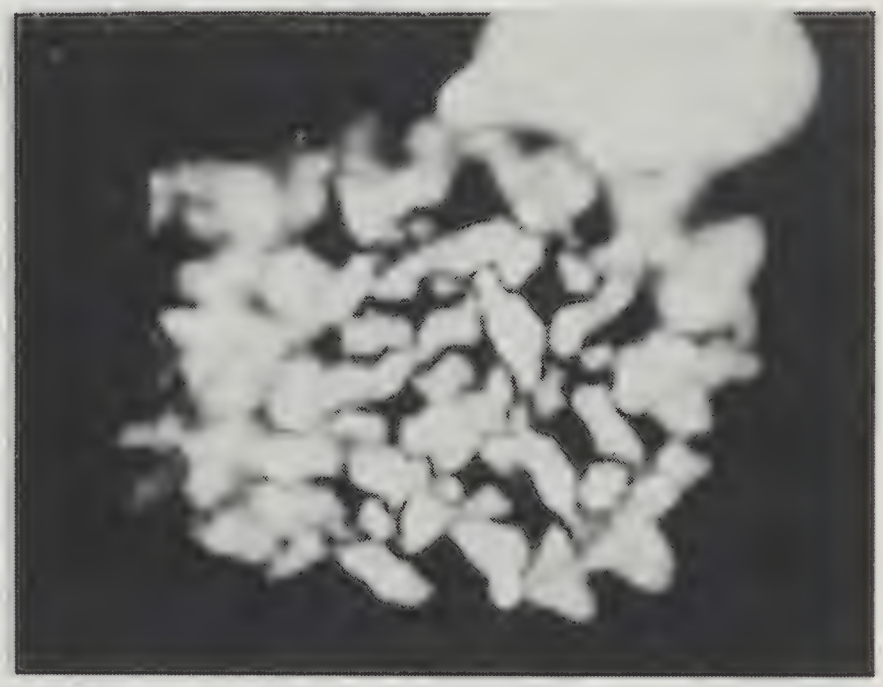

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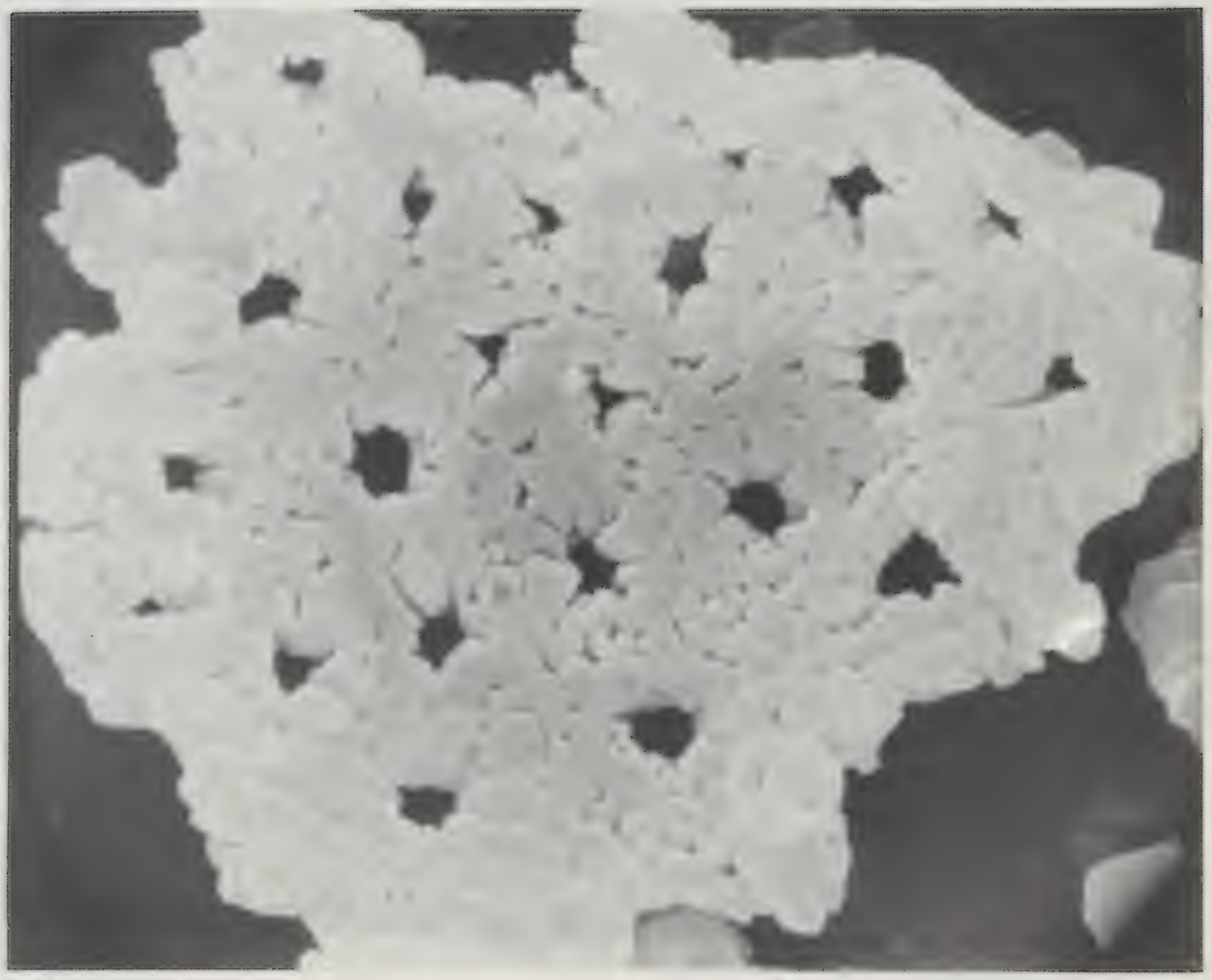


5

PLATE 7

Description: This elliptical coccolith is formed of a tall elliptical outer rim made of steeply inclined, overlapping flat elements. These overlay a cycle of irregular basal elements, which may fill part of the large central area. The central area is spanned by a thin cross made of bars that are not aligned with the axes of the ellipse and lie at angles to each other. The bars are made of elongate laths.

Size: Maximum length 6 microns.

Occurrence: This species was reported from the Paleocene of Denmark and was found in the Pine Barren Member of the Clayton Formation.

Genus NEOCOCCOLITHES
Sujkowski, 1931

Type species: Neococcolithes lososnensis Sujkowski, 1931

Definition: Thin elliptical rim with a large central opening spanned by an H-shaped structure.

NEOCOCCOLITHES PROTENUS
(Bramlette and Sullivan) Hay and Mohler
Plate 12, figures 1, 2

Zygolithus protenus BRAMLETTE and SULLIVAN, 1961, p. 150, pl. 6, figs. 15 a, b.
Chiphragmalithus protenus (Bramlette and Sullivan). SULLIVAN, 1964, p. 179, pl. 1, fig. 1.
Neococcolithes protenus (Bramlette and Sullivan). HAY and MOHLER, 1967, p. 1533, pl. 199, figs. 19-21; pl. 201, fig. 9. PERCH-NIELSEN, 1969, p. 64, pl. 5, fig. 4.

Description: This form has an elliptical rim constructed of strongly imbricate elements surrounding an inner cycle of more irregular elements. The central opening is spanned by an X-shaped structure that is made of elongate laths. The bars of the X are arranged so that they form a smaller angle with the short axis of the ellipse and a larger angle with the long axis.

Size: Maximum length 7 microns.

Occurrence: This species was reported from various worldwide Paleocene localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

Genus ZYGODISCUS
Bramlette and Sullivan, 1961

Type species: *Zygodiscus adamas* Bramlette and Sullivan, 1961

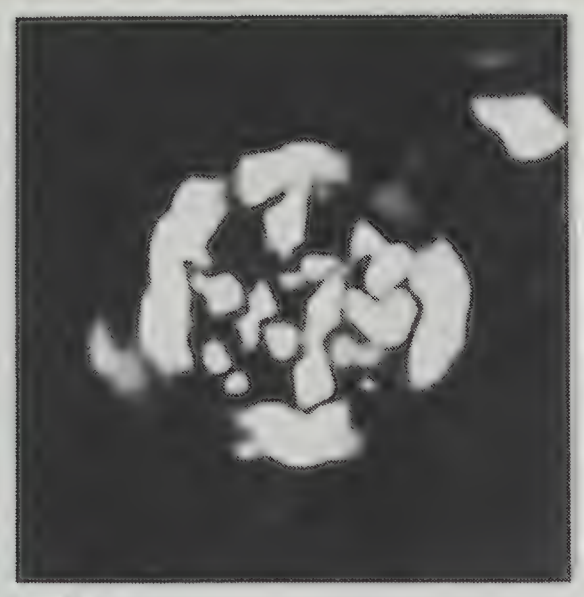
Definition: Coccoliths with an elliptical rim surrounding a central area with a vestige of a basal plate and a central opening spanned by a transverse bar. The bar has more than one segment of different calcite orientation.

ZYGODISCUS SIGMOIDES
Bramlette and Sullivan
Plate 14, figures 1-5

Zygodiscus sigmoides BRAMLETTE and SULLIVAN, 1961, p. 149, pl. 4, figs. 11 a-e. SULLIVAN, 1964, p. 187, pl. 5, figs. 7 a-c. BRAMLETTE and MARTINI, 1964, p. 303, pl. 4, figs. 4, 5. SULLIVAN, 1965, p. 38, pl. 6, figs. 8a, b, 9a, b. HAY and MOHLER, 1967, p. 1532, pl. 199, figs. 12-14. PERCH-NIELSEN, 1969a, p. 65, pl. 5, figs. 1-3; PERCH-NIELSEN, 1969b, p. 327, pl. 35, figs. 1-6.

PLATE 8

Figures 1, 2. *Thoracosphaera multiperforata* n. sp.
1a. Cross-polarized light, x3250; Sample CN-14
1b. Transmitted light, x3250; Sample CN-14
2. Electron micrograph, x18,800, Sample CN-7
Figure 3. *Thoracosphaera* cf. *T. imperforata* Kamptner; Sample CN-1
Cross-polarized light, x3250
Figure 4. *Micula decussata decussata* Vekshina; Sample CN-100
Phase-contrast, x3250
Figure 5. *Coccolithus orbiculatus* n. sp.; Sample CN-1
5a. Cross-polarized light, x3250
5b. Transmitted light, x3250
Figure 6. *Coccolithus* cf. *C. orbiculatus*; Sample CN-78
6a. Cross-polarized light, x3250
6b. Transmitted light, x3250



1a

1b

3

2

4

6a

5a

5b

6b

PLATE 8

Description: This elliptical coccolith has a low rim composed of a distal set of 30 to 35 elements, which show a strong dextral imbrication. Underlying these elements is a set of approximately 45 rectangular basal elements, which may partially close the large central opening. The central opening is spanned by a transverse bar composed of elongate laths that meet and form a short stem. The bar is highly arched and rises above the distal rim when viewed from the side. In the light microscope the crossbar may appear sigmoidal in shape.

Size: Maximum length 8 microns.

Occurrence: This species has been reported from the Paleocene of California, Alabama, Denmark, and France and was found in the Pine Barren and McBryde members of the Clayton Formation, the Matthews Landing Member of the Porters Creek Clay, and in the Porters Creek.

Family RHABDOSPHAERACEAE Lemmerman, 1903

Definition: Rhabdoliths with a circular basal plate composed of three or more cycles of radial elements, and a distally tapering stem.

Genus EIFFELLITHUS Reinhardt, 1965

Type species: *Zygolithus turriseiffeli* (Deflandre) Reinhardt, 1965

Definition: Rhabdolith with the basal disc constructed of a single cycle of imbricate elements that form a distally expanding rim. The central area is usually open and is spanned by two intersecting cross bars, which are symmetrical with the axes of the basal disc.

EIFFELLITHUS TURRISEIFFELI (Deflandre) Reinhardt
Plate 9, figure 3

Zygolithus turriseiffeli DEFLANDRE *in* DELFLANDRE and FERT, 1954, p. 149, fig. 65; pl. 13, figs. 15, 16.

Rhabdosphaera elliptica VERKSHINA, 1959, p. 74, pl. 1, fig. 10; pl. 2, figs, 14 a, b.

Zygrhablithus turriseiffeli DEFLANDRE, 1959, p. 135. MANIVIT, 1969, p. 191, pl. 1, fig. 1.

Zygrahablithus? turriseiffeli (Deflandre). BRAMLETTE and MARTINI, 1964, p. 304, pl. 3, figs. 18-21; pl. 4, figs. 1, 2.

Eiffellithus turriseiffeli (Deflandre). REINHARDT, 1965, p. 32. GARTNER, 1968, p. 26, pl. 2, figs. 22-23; pl. 3, fig. 13. THIERSTEIN, 1971, p. 475, pl. 7, figs. 9-11.

Clinorhabdus turriseiffeli (Deflandre). STOVER, 1966, p. 138, pl. 3, fig. 9.

Description: This rhabdolith has the elliptical disc composed of 60 to 80 dextrally imbricate elements. The rim is extended distally. The central area may be partly or completely covered. The X-shaped cross bars span the central area and may be symmetrical but not aligned with the axes of the basal disc. A hollow stem surmounts the centers of the cross bars.

Size: Maximum length 8 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Genus PREDISCOSPHAERA Vekshina, 1959

Type species: *Prediscosphaera decorata* Vekshina, 1959

PLATE 9

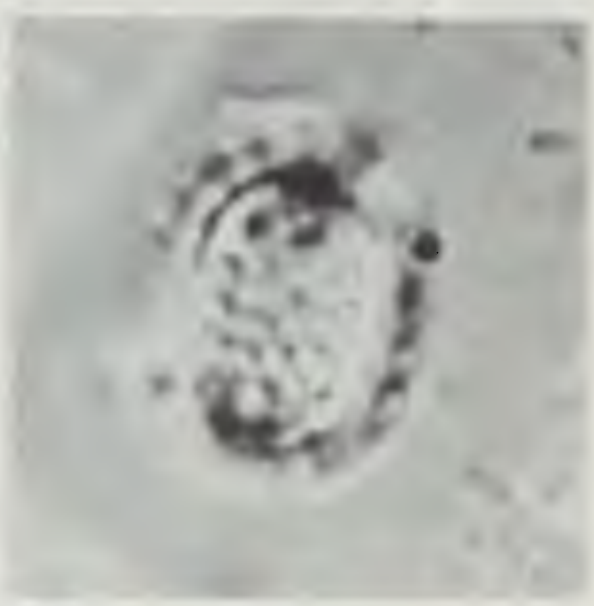
Figure 1. *Cribrosphaerella ehrenbergii* Arkhangelsky; Sample CN-11
- 1a. Cross-polarized light, x3250
- 1b. Transmitted light, x3250
- 1c. Interference-contrast, x3250

Figure 2. *Prediscosphaera cretacea* (Arkhangelsky) Gartner; Sample CN-10
- 2a. Cross-polarized light, x3250, 45° to polarizer
- 2b. Transmitted light, x3250
- 2c. Interference-contrast, x3250

Figure 3. *Eiffellithus turriseiffeli* (Deflandre) Reinhardt; Sample CN-7
- 3a. Cross-polarized light, x3250
- 3b. Transmitted light, x3250
- 3c. Phase-contrast, x3250
- 3d. Interference-contrast, x3250

1a

1b



1c

2a

2b

2c

3a

3b

3c

3d

PLATE 9

Definition: Rhabdoliths with a basal disc constructed of two cycles of elements separated bya groove. The open central area is spanned by two cross bars that intersect at the center and are surmounted by a stem.

PREDISCOSPHAERA CRETACEA
(Arkhangelsky) Gartner
Plate 9, figure 2

Coccolithophora cretacea ARKHANGELSKY, 1912, p. 410, pl. 6, figs. 12, 13.
Rhabdolithus intercisus DEFLANDRE *in* DEFLANDRE and FERT, 1954, p. 159, p. 13, figs. 12, 13; text figs. 91-92.
Discolithus cretaceus (Arkhangelsky). GORKA, 1957, p. 251, pl. 2, fig. 11. BLACK and BARNES, 1959, p. 326, pl. 11, figs. 1, 2.
Prediscosphaera decorata VEKSHINA, 1959, p. 73, p. 1, figs. 8, 9; pl. 2, figs. 13a.
Zygrhablithus intercisus (Deflandre). DEFLANDRE, 1959, p. 136, pl. 1, figs. 5-20.
Deflandrius cretaceus (Arkhangelsky). BRAMLETTE and MARTINI, 1964, p. 301, pl. 2, figs. 11, 12.
Deflandrius intercisus (Deflandre). BRAMLETTE and MARTINI, 1964, p. 301, pl. 2, figs. 13-16.
Prediscosphaera cretacea (Arkhangelsky). GARTNER, 1968, p. 19, pl. 2, figs. 10-14; pl. 3, fig. 8. THIERSTEIN, 1971, p. 479, pl. 7, fig. 7.

Description: This form has a broadly elliptical to subcircular basal disc consisting of two cycles of approximately 16 trapezoidal elements. The proximal cycle is smaller than the distal. The central area is spanned by X-shaped cross bars, which consist of a proximal and distal set of bars that have a square or rounded hole at the intersection.

Size: Maximum diameter 7 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Family PRINSIACEAE
Hay and Mohler, 1967
Genus PRINSIUS Hay and Mohler, 1967

Type species: *Coccolithus bisulcus* Stradner, 1963

Definition: Elliptical placoliths, with simple, solidly constructed distal shield; interference figure between crossed polarizers dextrogyre; proximal shield bright, distal shield somewhat fainter.

PRINSIUS DIMORPHOSUS (Perch-Nielsen)
Plate 5, figure 1-3

Biscutum? dimorphosum PERCH-NIELSEN, 1969a, p. 57, pl. 4, figs. 6-12; PERCH-NIELSEN, 1969b, p. 318, pl. 32, figs. 1-3a.
Prinsius dimorphosus (Perch-Nielsen). PERCH-NIELSEN, 1977, p. 794, pl. 30, figs. 10-13.

Description: The distal shield of this small elliptical to rounded placolith is composed of 8-12 flattened trapezoidal elements. A second cycle of elements is present near the center. These are elongated and inclined dextrally. The central opening is small occupying only about one-tenth of the shield. The proximal shield is much smaller and is composed of a single cycle of elements equal in number to those in the distal shield.

Discussion: This species differs from *Prinsius martinii* in having few elements, in lacking the central granular elements, and in being less elliptical.

Size: Maximum diameter 4 microns.

Occurrence: Representatives of this species were found in samples CN-1 and CN-100 from the McBryde Member of the Clayton Formation.

PRINSIUS MARTINII (Perch-Nielsen) Haq
Plate 10, figures 1-4

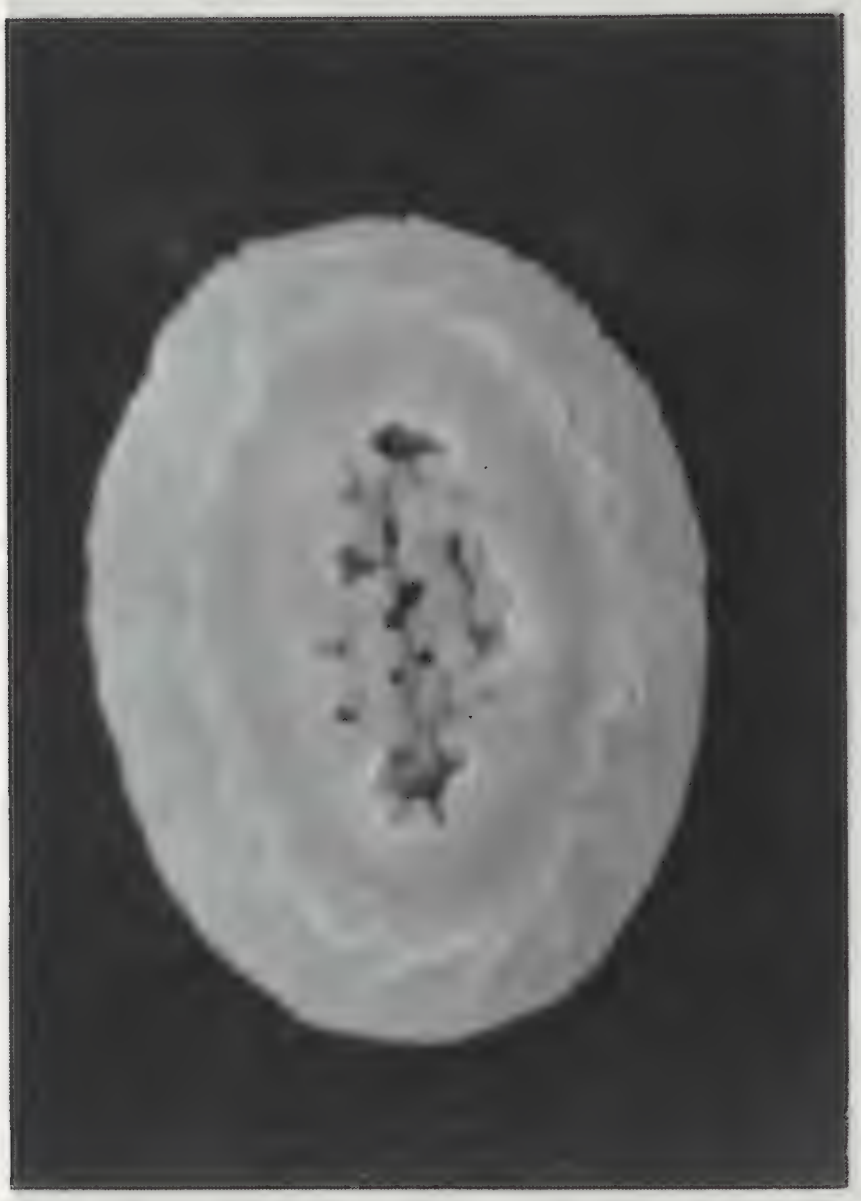
PLATE 10

Figures 1-4. *Prinsius martinii* Perch-Nielsen
1a. Cross-polarized light, x3250, 40° to polarizer; Sample CN-26
1b. Phase-contrast, x3250; Sample CN-26
2. Cross-polarized light, x3250; Sample CN-26
3. Electron micrograph, x18,300, Sample CN-32, distal view
4. Electron micrograph, x18,300, Sample CN-32, distal view
Figure 5. *Markalius reinhardtii* Perch-Nielsen; Sample CN-14
5a. Cross-polarized light, x3250, low focus
5b. Cross-polarized light, x3250, high focus
5c. Phase-contrast, x3250

1a

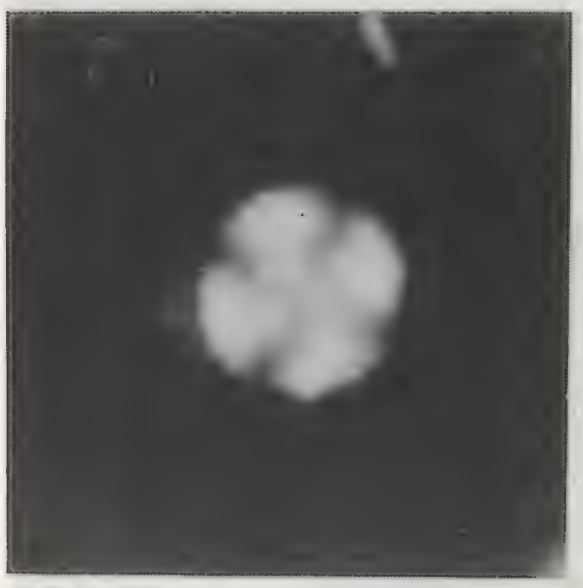
1b

2



3

4



5a

5b

5c

PLATE 10

Ericsonia? martinii PERCH-NIELSEN, 1969a, p. 61, pl. 4, figs. 13, 14; PERCH-NIELSEN, 1969b, p. 324, pl. 32, figs. 3b, 5, 6, 7. HAQ, 1971, p. 18, pl. 5, figs. 1, 5, 6, 7, 10.
Prinsius martinii (Perch-Nielsen). PERCH-NIELSEN, 1977, p. 794, pl. 30, fig. 3.

Description: The distal shield of this small elliptical placolith is composed of 15 to 25 flattened trapezoidal elements. A second cycle of elements is present near the center. These elements are triangular in shape and are inclined dextrally. Inside of and immediately adjacent to this second set of elements is a set of irregular elements that may overlay the second set and extend into the central opening. The central opening may be filled or partially filled with irregular granular elements, which may or may not be part of the previous irregular elements.

Discussion: Perch-Nielsen described this species as having columnar elements that meet in the middle along the major axis of the ellipse. Some of the specimens seen in the Alabama Midway do not have central elements meeting, probably due to partial solution.

Size: Maximum length 3 microns.

Occurrence: Representatives of this species were found in all three samples of the McBryde Member of the Clayton Formation, and in the Matthews Landing Member of the Porters Creek Clay.

PRINSIUS cf. PRINSIUS MARTINII
Plate 3, figures 3, 4
Plate 6, figure 5

Description: This elliptical placolith has a distal shield of 20 to 25 elements. The central area may be open or partially closed by elongate elements. Under the light microscope these forms appear mainly as elliptical rings.

Discussion: These forms are very similar in size, shape, and number of elements to *Prinsius martinii* and probably represent partially dissolved or poorly preserved specimens of that species.

Size: Maximum length 4 microns.

Occurrence: Representatives of this form were found in 8 of the 10 samples from the Pine Barren Member of the Clayton Formation.

Genus TOWEIUS Hay and Mohler, 1967

Type species: *Toweius craticulus* Hay and Mohler, 1967

Definition: Circular to subcircular placoliths whose shields are constructed of petaloid or trapezoidal elements, which are nonimbricate to slightly imbricate. The central area contains a reticulate grill.

TOWEIUS PETALOSUS Ellis and Lohman
Plate 6, figure 4

Toweius petalosus ELLIS and LOHMAN, 1973, p. 107, pl. 1, figs. 1-11.

Description: This small elliptical placolith has a distal shield composed of 9 to 17 petaloid plates or elements, which originate in the central area and extend outwards showing a slight sinistral imbrication. The petaloid plates expand in width towards the outer edge of the distal shield. These plates extend beyond the outer edge of the distal shield giving the palcolith a crown-like appearance. The proximal shield is smaller and is composed of what appear to be two cycles of relatively flat elements that are approximately the same in number as the distal shield.

PLATE 11

Figures 1, 2. *Cruciplacolithus tenuis* var. b; Sample CN-78
1a. Cross-polarized light, x3250, 70° to polarizer
1b. Transmitted light, x3250
1c. Interference-contrast, x3250
2. Electron micrograph, x9200, distal view
Figure 3. *Cruciplacolithus tenuis* var. c; Sample CN-18
3a. Cross-polarized light, x3250
3b. Transmitted light, x3250
Figure 4. *Cruciplacolithus tenuis* var. a; Sample CN-14
4a. Cross-polarized light, x3250
4b. Phase-contrast, x3250

1a

1b

1c

2

3a

3b

4a

4b

PLATE 11

Size: Maximum length 3 microns.

Occurrence: This species was reported from the Clayton Formation and Porters Creek Clay by Ellis and Lohman and was found in the Pine Barren Member of the Clayton Formation in the present study.

Family BRAARUDOSPHAERACEAE
Deflandre, 1947
Genus BRAARUDOSPHAERA
Deflandre, 1947

Type species: *Braarudosphaera bigelowi* (Gran and Braarud) Deflandre, 1947.

Definition: Pentaliths consisting of five quadrangular segments or elements whose outer edges are straight or slightly curved. The elements meet at straight sutures, which run from the center to the angles or the outer edges. The elements have no perforations or depressions.

BRAARUDOSPHAERA BIGELOWII
(Gran and Braarud) Deflandre
Plate 2, figure 4

Pontosphaera bigelowi GRAN and BRAARUD, 1935, p. 389, text fig. 67.

Braarudosphaera bigelowi (Gran and Braarud). DEFLANDRE, 1947, p. 439, figs. 1-5. DEFLANDRE, 1950, p. 1156, text figs. 1-4. BRAMLETTE and RIEDEL, 1954, p. 393, pl. 38, figs. 1a, b. BRAMLETTE and SULLIVAN, 1961, p. 153, pl. 8, figs. 1a, b, 2-5. SULLIVAN, 1964, p. 188, pl. 8, figs. 1a, b. HAY and MOHLER, 1967, p. 1535, pl. 202, figs. 12, 16, 20. PERCH-NIELSEN, 1971b, p. 942, fig. 1. BYBELL and GARTNER, 1972, p. 323, pl. 1, figs. 1, 2.

Description: These pentaliths are composed of five elements separated by distinctive sutures that run from the center to the outer edges. The periphery of the pentalith varies from slightly rounded to angular.

Size: Maximum diameter 7 microns.

Occurrence: This species is present in Cretaceous through Holocene sediments, and was found in the Matthews Landing Member of the Porters Creek Clay.

BRAARUDOSPHAERA TURBINEA Stradner
Plate 3, figure 5

Braarudosphaera turbinea STRADNER, 1963, p. 10, pl. 6, fig. 8.

Description: This pentalith consists of five triangular elements, which are sinistrally imbricate. The outer edge of the overlapping side tends to be slightly pointed.

Size: Maximum diameter 7 microns.

Occurrence: This species was originally reported from the Paleocene of Austria and was found in the Pine Barren Member of the Clayton Formation.

Family PONTOSPHAERACEAE
Lemmermann, 1903
Genus DISCOLITHINA
Loeblich and Tappan, 1963

Type species: *Discolithus vigintiforatus* Kamptner, 1948.

Definition: Elliptical disc with or without distinct rim, generally perforated.

DISCOLITHINA VERSA
(Bramlette and Sullivan), n. comb.
Plate 2, figure 3

Discolithus versa BRAMLETTE and SULLIVAN, 1961, p. 144, pl. 3, fig. 16. SULLIVAN, 1964, p. 183, pl. 4, fig. 11. SULLIVAN, 1965, p. 35, pl. 5, figs. 8, 9.

Pontosphaera versa (Bramlette and Sullivan). SHERWOOD, 1974, p. 31, pl. 5, figs. 1, 2; pl. 4, fig. 10.

PLATE 12

Figures 1, 2. *Neococcolithes protenus* (Bramlette and Sullivan) Hay and Mohler; Sample CN-78

1a. Cross-polarized light, x3250
1b. Transmitted light, x3250
1c. Phase-contrast, x3250
2. Electron micrograph, x9500, distal view

Figures 3, 4. *Heliorthus concinnus* (Martini) Hay and Mohler; Sample CN-78

3a. Cross-polarized light, x3250
3b. Transmitted light, x3250
3c. Phase-contrast, x3250
4. Electron micrograph, x18,800

1a

1b

1c

3a

3b

3c

2

4

PLATE 12

Description: This elliptical discolith has a distinct rim that encloses the base plate. The base plate contains a sigmoidal slit, which appears widest at each end.

Size: Maximum length 7 microns.

Occurrence: This species is present from the Paleocene through the Oligocene and was found in the Matthews Landing Member of the Porters Creek Clay.

Family SYRACOSPHAERACEAE
Lemmermann, 1903
Genus CRIBROSPHAERELLA
Deflandre, 1952

Type species: *Cribosphaera ehrenbergi* Arkhangelsky, 1912.

Definition: Elliptical disc with a cribrate central plate and a rim of two or three tiers. Each tier is constructed of a single cycle of elements, which meet along irregular sutures. The central plate may or may not have perforations.

CRIBROSPHAERELLA EHRENBERGII
(Arkhangelsky) Deflandre
Plate 9, figure 1

Cribrosphaera ehrenbergi ARKHANGELSKY, 1912, p. 412, pl. 6, fig. 19.

Cribrosphaerella ehrenbergi (Arkhangelsky). DEFLANDRE, 1952, p. 111, text fig. 54a (*non* 54b). GORKA, 1957, p. 260, pl. 4, fig. 12. GARTNER, 1968, p. 40, pl. 1, figs. 14-15; pl. 3, fig. 2; pl. 6, fig. 7; pl. 12, fig. 2; pl.15, fig. 11. CEPEK, 1970, p. 239, pl. 22, figs. 1, 2; pl. 26, fig. 1.

Description: This form has an elliptical disc with a rim of two tiers, each constructed of a single cycle of elements. The central area is covered by a complex perforated plate.

Size: Maximum length 7 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren Member of the Clayton Formation.

Family THORACOSPHAERACEA
Schiller, 1930
Genus THORACOSPHAERA
Kamptner, 1927

Type species: *Thoracosphaera pelagica* Kamptner, 1927.

Definition: Coccolithophorids with a spherical test composed of regular to irregularly-shaped polygonal elements of calcite.

THORACOSPHAERA MULTIPERFORATA, n. sp.
Plate 7, figures 3, 4, 5;
Plate 8, figures 1, 2

Description: These coccolithophorids are composed of small elongate but irregular elements which are arranged radially around small perforations. Smaller more equidimensional elements are present where the elongate elements meet. In cross polarized light the elements appear as four very elongate units framing the perforations.

Size: Maximum observed length of element - 1 micron.

Holotype: USNM 388225 - CN-7A 296 (1.5 x 9.4)(Plate 7, figure 3)

Paratypes: CN-14-31 (20.4 x 12.7)(Plate 7, figure 4). SEM CN-7-5 (Plate 7, figure 5)

Occurrence: Representatives of this species were found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

THORACOSPHAERA SAXEA Stradner
Plate 7, figure 2

PLATE 13

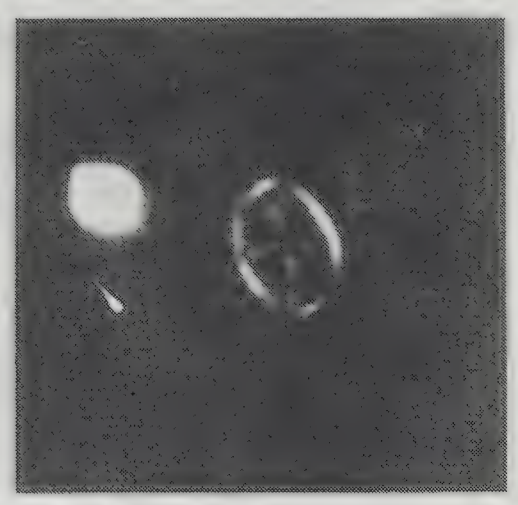
Figure 1. *Coccolithus* sp.; Sample CN-26
1a. Cross-polarized light, x3250
1b. Cross-polarized light, x3250, 45° to polarizer
1c. Phase-contrast, x3250

Figures 2-5. *Heliothus denticulatus* Perch-Nielsen
2a. Cross-polarized light, x3250; Sample CN-14
2b. Phase-contrast, x3250; SampleCN-14
3. Electron micrograph, x19,200, Sample CN-14, proximal view
4a. Cross-polarized light, x3250; Sample CN-10
4b. Phase-contrast, x3250; Sample CN-10
5. Electron micrograph, x8000, Sample CN-14, distal view

1a

1b

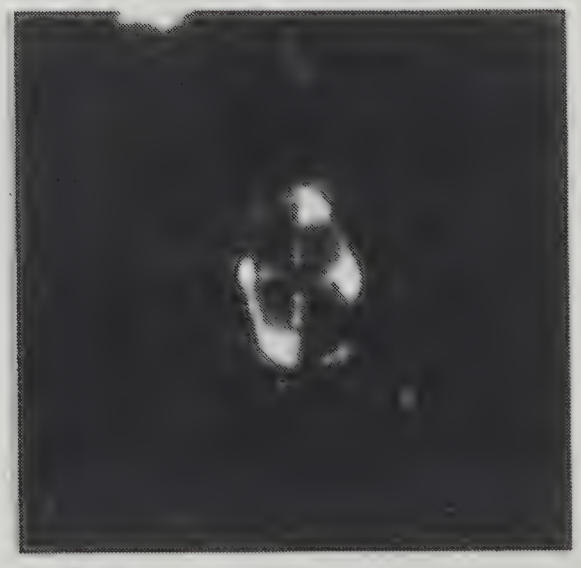
1c



2a

2b

3



4a

4b

5

PLATE 13

Thoraosphaera sp. BRAMLETTE and RIEDEL, 1954, p. 393, pl. 38, fig. 5.
Thoracosphaera saxea STRADNER, 1961, p. 84, text fig. 71. COHEN, 1964, p. 248, pl. 5, figs 6 a-e; pl. 6, fig. 6. HAY and MOHLER, 1967, p. 1534, pl. 203, fig. 5. SACHS and SKINNER, 1973, p. 147, pl. 5, figs. 10-12.

Description: This form consists of small irregular imperforate elements that form a spherical test. The contacts between the elements may appear crenulated.

Size: Maximum observed length of element - 1 micron.

Occurrence: This species is found in Cretaceous to Holocene sediments and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

THORACOSPHAERA cf. THORACOSPHAERA IMPERFORATA Kamptner
Plate 7, figure 1; Plate 8, figure 3

cf. *Thoracosphaera imperforata* KAMPTNER, 1955, p. 37, pl. 8, fig. 98.
Thoracosphaera cf. *T. imperforata* Kamptner. BRAMLETTE and MARTINI, 1964, p. 305, pl. 5, figs. 1, 2.

Description: These large irregular elements form a mosaic of interlocking units. The size of the elements is fairly uniform and the edges appear smooth. Under cross-polarized light the elements appear as larger somewhat elongated units, surrounded by a dark line.

Discussion: The elements of this species are larger and seem to have smoother edges than those of *Thoacosphaera saxea*.

Size: Maximum width of element - 2 microns.

Occurrence: This species was described from the Cretaceous and Paleocene in various worldwide localities and was found in the Pine Barren and McBryde members of the Clayton Formation, and the Matthews Landing Member of the Porters Creek Clay.

Genera INCERTAE SEDIS
Genus MICULA Vekshina, 1959

Type species: *Micula decussata* Vekshina, 1959

Definition: Cube, with concave or plane faces and constructed of calcite laminae that are not crystallographically continuous.

MICULA DECUSSATA DECUSSATA Vekshina
Plate 8, figure 4

Micula decussata VEKSHINA, 1959, p. 71, pl. 1, fig. 6; pl. 2, fig. 11.
Discoaster staurophorus GARDET, 1955, p. 534, pl. 10, fig. 96.
Trochoaster staurophorus (Gardet). STRADNER, 1959, p. 480, figs. 49-50. MARTINI, 1960, p. 82, pl. 10, fig. 37.
Nannotetraster staurophorus (Gardet). MARTINI and STRADNER, 1960, p. 266, fig. 1. STRADNER and PAPP, 1961, p. 101, pl. 31, figs. 2-4.
Micula staurophora (Gardet) STRADNER. 1963, p. 179, pl. 4, fig. 12a. BRAMLETTE and MARTINI, 1964, p. 318, pl. 6, fig. 7-11.
Micula decussata Vekshina. GARTNER, 1968 (partim), p. 47, pl. 2, figs. 5-8; pl. 4, fig. 17; pl. 9, fig. 18; pl. 14, fig. 13; pl. 18, fig. 7; pl. 20, fig.15.
Micula decussata decussata Vekshina. BURKRY, 1969, p. 67, pl. 40, figs. 5, 6.

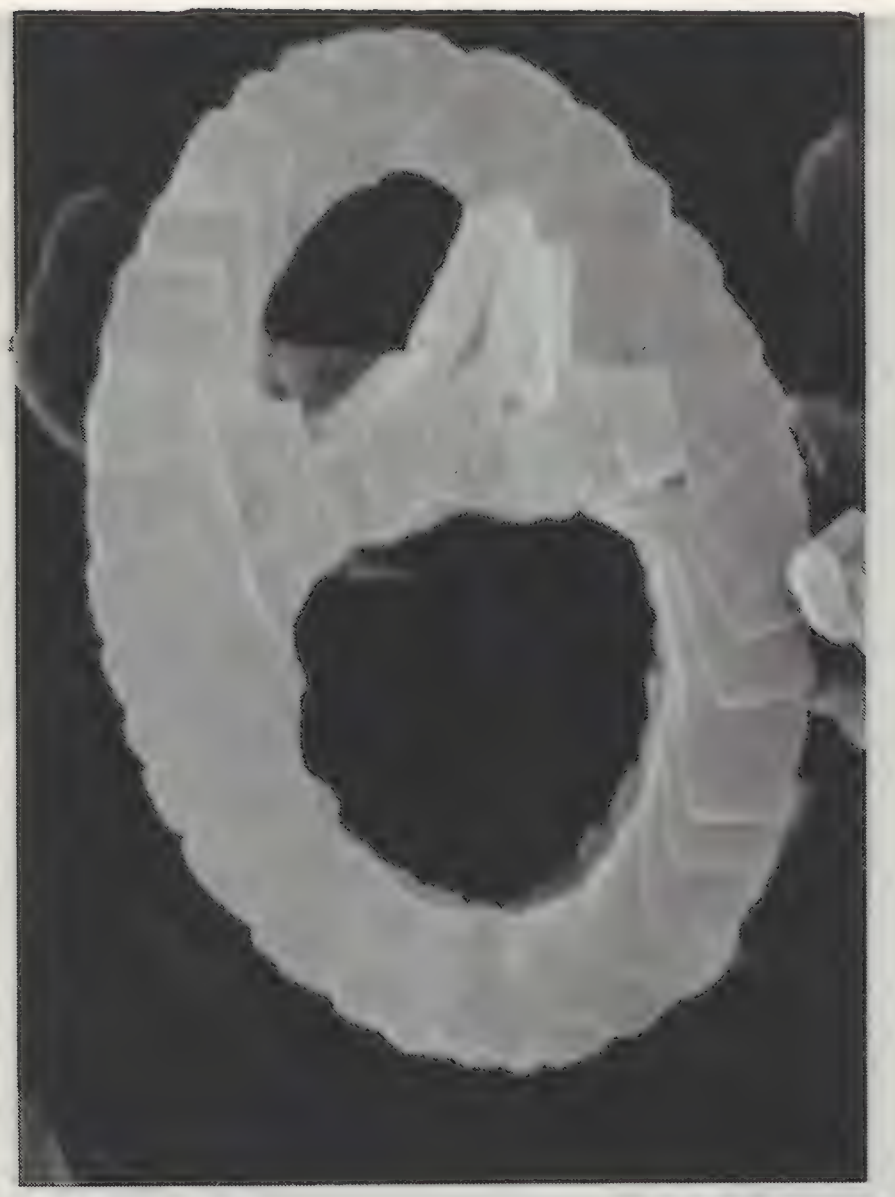
Description: This cube has concave faces and orthogonal or slightly extended corners. The concave faces make the form appear to be a four-rayed star under the light microscope.

Size: Maximum width 4 microns.

Occurrence: This species is common in the Cretaceous and was found in the Pine Barren and McBryde members of the Clayton Formation.

PLATE 14

Figures 1-5. *Zygodiscus sigmoides* Bramlette and Sullivan
1. Electron micrograph, x9500, Sample CN-7, distal view
2. Electron micrograph, x9300, Sample CN-7, distal view
3a. Cross-polarized light, x3250; Sample CN-78
3b. Transmitted light, x3250; Sample CN-78
4. Electron micrograph, x9200, Sample CN-7, proximal view
5a. Cross-polarized light, x3250; Sample CN-7
5b. Transmitted light, x3250; Sample CN-7



1

2

3a

3b

4

5a

5b

PLATE 14

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REVIEW

GEOLOGISTS AND IDEAS: A HISTORY OF NORTH AMERICAN GEOLOGY, edited by Ellen T. Drake and William M. Jordan. This is Centennial Special Volume 1 (CSV 1), the first of the series of 71 volumes, transects, and maps to be published under the aegis of the Decade of North American Geology (DNAG) project of the Geological Society of America, Boulder, Colorado, 1985, x + 525 pp., 8 3/4 x 11 1/4 inches, illus., index, casebound, $37.50

This volume is the Centennial contribution from the History of Geology Division of the Geological Society of America. In addition to four topical special volumes, of which this is one, there will be 28 volumes on the *Geology of North America*, comprising a synthesis of the present state of knowledge of the geology and geophysics of the continent and the adjacent oceanic regions (a joint project of the Geological Society of America and the Geological Survey of Canada). Six volumes of *Centennial Field Guides"*, each describing geologic sites within one of the six regional sections of the Society, twenty-four packets of continent-ocean transects across the continental margins and seven maps of North America, each set with accompanying separate volumes, complete the DNAG series of 71 volumes and packets.

The present volume, prepared and presented by the History of Geology Division of the Society, includes thirty-three scholarly papers, arranged in four sections, *The Evolution of Scientific Ideas* (9), *Contributions of Individuals* (9), *Contributions of Organized Groups* (8), and *Application of Significant Ideas* (7), followed by an index. As the editors state so well, "the papers range in subject matter from geosynclines to plate tectonics, from the origin of life to the origins of caves and craters, from James Hall to George Gaylord Simpson, from the Arctic to Mexico, and from deep-sea drilling to orbital remote sensing." The broad scope of this important volume is both impressive and satisfying, and it surely represents a most worthy expression of the Centennial celebration.

The Evolution of Scientific Ideas begins with the origins of Isostasy and the Geosyncline, two original concepts uniquely American in their origin and which still hold an important place in the conceptual background of plate tectonics. Dwight Mayo presents the complementary relationships of these "made in America" ideas, their contemporary origins, and traces their historical development from James Hall and Clarence Dutton to their present position in structural theory. Subsequent papers deal with Evolving Tectonic Concepts of the Central and Southern Appalachians from the earliest and primitive catastrophist ideas of the brothers Rogers and others to the modern thesis of accretionary and allochthonous belts of micro-continents and their interrelationship with plate theory; the application of the mélange concept and the role of underthrusting in the origin of the Franciscan Series in California, including its varied lithologies and age relationships; the Coon Butte Crater Controversy; the Development of Quantitative Geomorphology; the History of American Theories of Cave Origin, from the two-cycle deep-phreatic solution origin desribed by William Morris Davis to the more recent empirical demonstrations of cave formation through solutional and mechanical action near and above the water table; the development of Glacial Geology and the North American Craton from the primitive notions of glacial erratics and drift formed through the action of icebergs early in the century to detailed description and maps compiled in the mid- to late nineteenth century leading ultimately to favor for Richthofen's eolian hypothesis for the origin of loess and to Chamberlin's recognition of multiple glacial advances separated by warmer, nonglacial periods and the formal classification for the Pleistocene in North America; J. Tuzo Wilson's personal account of the development of Ideas about the Canadian Shield during the past sixty years; and concluding with Pres Cloud's Vestiges of a Beginning, a charming review of what we have learned about the

(Continued on p. 62)

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

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TAPHONOMIC CHARACTERISTICS OF OFFSHORE MOLLUSK SHELLS, SAPELO ISLAND, GEORGIA[1]

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I. ABSTRACT

Detrital mollusk valves from a small area on the offshore (palimpsest) shelf near Sapelo Island were analyzed with respect to (1) proportions of new and old shells, (2) degree of encrustation or boring by subsequent organisms, and (3) general provenance of shell assemblages. Old shells predominated at both landward and seaward sites, whereas new shells predominated at intermediate sites; many new and most old shells were invested with encrustings (mainly bryozoans, serpulids) and/or borings (mainly sponges, barnacles). Valves of nearshore species were most abundant at landward sites, but valves of offshore species were somewhat more evenly distributed. These observations suggest that (1) nearshore and offshore components remain essentially in-situ, (2) old shells tend to be more intensely bored or encrusted than new shells, (3) proportions of old and new shells, and bored or encrusted shells, are governed principally by the duration of their exposure to physical and biological processes at the sediment-water interface, which is enhanced by extremely slow rates of deposition in this area, but that (4) such conclusions must be based upon the character of the total assemblage, not the condition of individual shells.

II. INTRODUCTION

The carbonate fractions of Atlantic beach and continental shelf sediments have been the object of numerous mineralogic and sedimentologic investigations (e.g., Pilkey *et al.*, 1967, 1968; Frey and Pinet, 1978). Of particular interest to

[1]Contribution number 541, University of Georgia Marine Institute, Sapelo Island.

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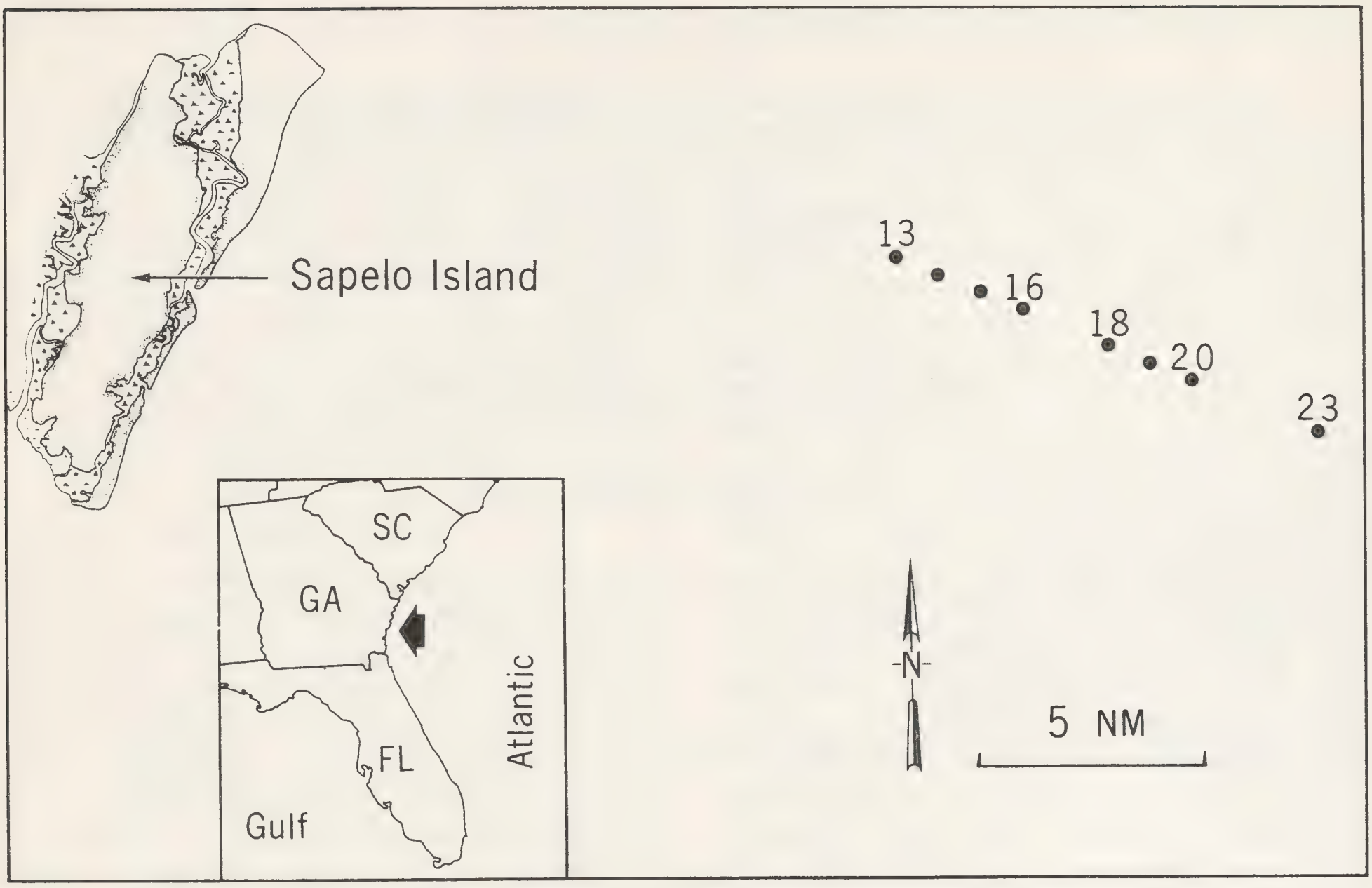

Fig. 1. Index map of study area, Sapelo Island, Georgia. Station designations refer to the number of nautical miles offshore.

both sedimentologists and paleontologists is the condition of skeletal allochems as an approximate indicator of environmental processes and depositional history (Pilkey *et al.*, 1979). Among the more important parameters of mollusk shell condition are degrees of abrasion, fragmentation, and rounding, proportions of fresh and old shells, amount of shell staining or discoloration, and intensity of boring or encrustation by other organisms (Pilkey *et al.*, 1969a, 1969b).

Most studies cited above refer to regional aspects of these carbonate fractions and their broad implications. The present report, in contrast, is concerned chiefly with conditions of mollusk shells on a small segment of the shelf off Sapelo Island, Georgia (Fig. 1). Major objectives included (1) differentiation of new and old shell components within the total assemblage, (2) characterization of shell encrustation and boring by other organisms, (3) evaluation of nearshore and offshore species distributions, and (4) reconstruction of physical and biological aspects of shell provenance. Despite limitations of the data set (Appendix) this analysis of local assemblages should help augment or clarify many of the shell parameters outlined previously, particularly as they relate to local fossil accumulations typically encountered by paleontologists (Fürsich, 1978; Kidwell, 1982; Kidwell and Jablonski, 1983).

III. METHODS AND SETTING

Eight stations along a transect off the northern end of Sapelo Island (Fig. 1) were sampled by means of a NEL spade corer (see Smith and Howard, 1972; Howard and Frey, 1975). Each sample consisted of $\sim$0.015 m^3 of sediment. Shells were recovered by sieving sediments through a 2.5 mm mesh screen; only distinct, readily identifiable shells were retained for analysis, in contrast with the whole-sample analyses by Pilkey (1964) and Pilkey *et al.* (1969b). Individual bivalve valves were tallied as separate specimens, although articulated shells were recorded; these bivalve abundance data, therefore, might be halved with respect to the gastropod

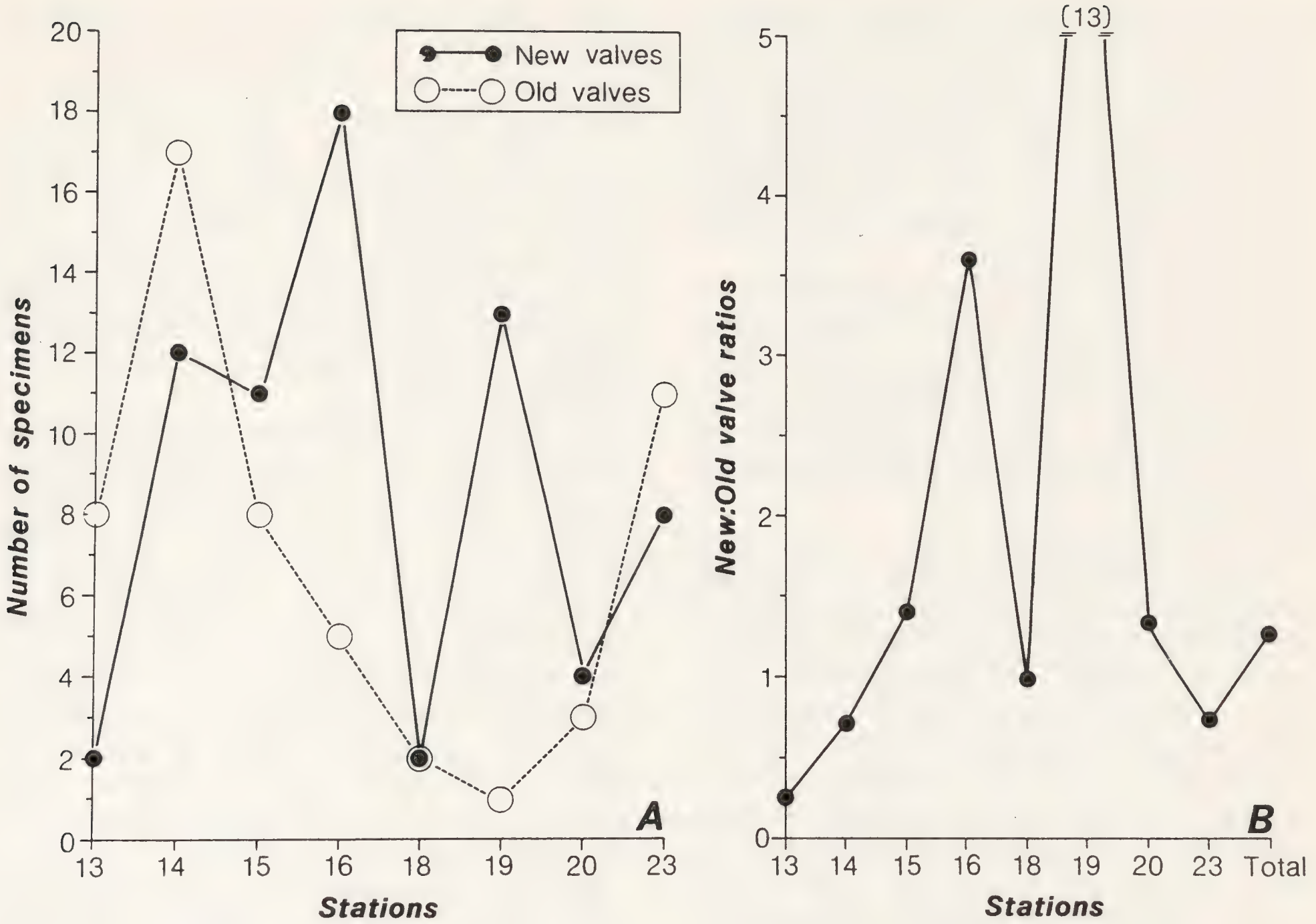

Fig. 2. Relative abundance of detrital mollusk shells. Individual bivalve valves were tallied as separate specimens (see methods). (A) Frequency of new and old valves. (B) Ratio of new to old valves; values greater than 1 = predominance of new valves and values greater than 1 = predominance of old valves.

abundance data. For taxonomic consistency, all species names were adopted from Abbott (1974).

Environmentally, all samples are from the lower offshore zone, albeit slightly seaward of the area described by Howard and Reineck (1972); this area is essentially equivalent to the inner-middle shelf zone discussed by Pilkey *et al.* (1969b) and Howard and Frey (1980). Water depths are on the order of 12 to 15 m. Sediments consist principally of clean, palimpsest (Pleistocene), medium- to coarse-grained, bioturbated sand, inhabited by modern benthic organisms (Dörjes, 1972). Shell assemblages thus exhibit considerable temporal mixing; environmental mixing also resulted from Pleistocene transgressions and regressions across the shelf (Blackwelder *et al.*, 1979). Such mixed assemblages are difficult to decipher because individual species of mollusks remained extant throughout Quaternary time. [In inlet-channel scours, they also are admixed with Tertiary fossils (Frey *et al.*, 1975).]

IV. RESULTS AND DISCUSSION

In these analyses, major emphasis was placed upon identifiable mollusk shells. Less diagnostic fragments were discarded, without regard for their total abundance or distribution. Except for scattered small, thin fragments of echinoid tests, presumably the heart urchin *Moira atropos* (Dörjes, 1972), other skeletal carbonates were comparatively minor macroscopic constituents of the sediment. However, one nearly intact, albeit old, test of the sand dollar *Mellita sexiesperforata* was recovered at Station 23 [nearshore sand dollars,in contrast, are referable to *M. quinquiesperforata* (cf. Bell and Frey, 1969).]

Relatively few stained or discolored mollusk shells were observed. Of 125 speci-

mens analyzed, three valves of *Mulinia lateralis* were brown, and one valve of *M. lateralis*, one of *Crassostrea virginica*, and two of *Anomia simplex* were black (*cf.* Pilkey *et al.*, 1969b). Thus, the host substrates apparently remained predominantly within the oxidizing zone during accumulation of the shell assemblages.

Most bivalve shells were disarticulated and scattered; where left and right valves of the same species were present, most were of different sizes. The only exceptions were one articulated specimen of *Linga pensylvanica* and two of *Laevicardium pictum*.

New Versus Old Shells

Many workers have noted the contrast between fresh- and old-shell assemblages on the Atlantic shelf (*e.g.*, Pilkey, 1964; Pilkey *et al.*, 1969b). The same is true of the lower offshore zone on the Georgia shelf (Appendix). Of total shells recovered during this study, 56% were classified as new and 44% were classified as old specimens.

Criteria for temporal classifications of shells vary among authors. Recent experience on the Georgia coast (Henderson and Frey, 1986) suggests that such features as shell breakage, staining, dissolution, and encrustation or boring have inconsistent temporal implications and, therefore, are somewhat unreliable indices of relative age. Instead, fresh shells are best indicated by retention of original color, varnish, or gloss, or organic constituents such as ligament or periostracum; old shells lack these features and also may be bleached or chalky in appearance (*cf.* Trewin and Welsh, 1972).

All kinds of criteria remain subjective to some extent. Yet, those adopted for the present study seem to work well, on the whole, and were applied consistently throughout the analysis. [Early attempts at ^{14}C dating (*cf.* Panin *et al.*, 1983) proved to be prohibitively expensive because of extreme temporal mixing of the assemblages; thorough radiometric analysis would require the systematic dating of numerous shells from each sample, together with careful evaluation of possible diagenetic changes (Ragland *et al.*, 1979).]

By the above criteria, old shells predominated at both the landward and sea-

Table 1. Summary of encrustations and borings invested upon detrital mollusk valves off Sapelo Island.

	Gastropods		Bivalves		Total	
Investments*	New N(%)	Old N(%)	New N(%)	Old N(%)	New N(%)	Old N(%)
ENCRUSTATIONS:						
bryozoans	3(21)	3(43)	11(20)	31(65)	14(20)	34(62)
serpulids	1 (7)	1(14)	10(18)	27(56)	11(16)	28(51)
bivalve spat	–	1(14)	5 (9)	8(17)	5 (7)	9(16)
barnacles	–	1(14)	–	7(15)	–	8(15)
BORINGS:						
sponges	–	4(57)	1 (2)	17(35)	1 (1)	21(38)
barnacles	1 (7)	1(14)	–	7(15)	1 (1)	8(15)
gastropods	–	–	7(13)	3 (6)	7(10)	3 (5)
gastrochaenids	–	–	3 (5)	3 (6)	3 (4)	3 (5)
algae-fungi	–	–	1 (2)	6(13)	1 (1)	6(11)
Total encrusted valves	4(29)	(43)	17(30)	35(73)	21(30)	38(69)
Total bored valves	1 (7)	4(57)	10(18)	26(54)	11(16)	30(55)
Total invested valves	5(36)	5(71)	21(38)	36(75)	26(37)	41(75)

*Some valves exhibited only encrustations and other valves only borings, yet most exhibited various combinations of the two.

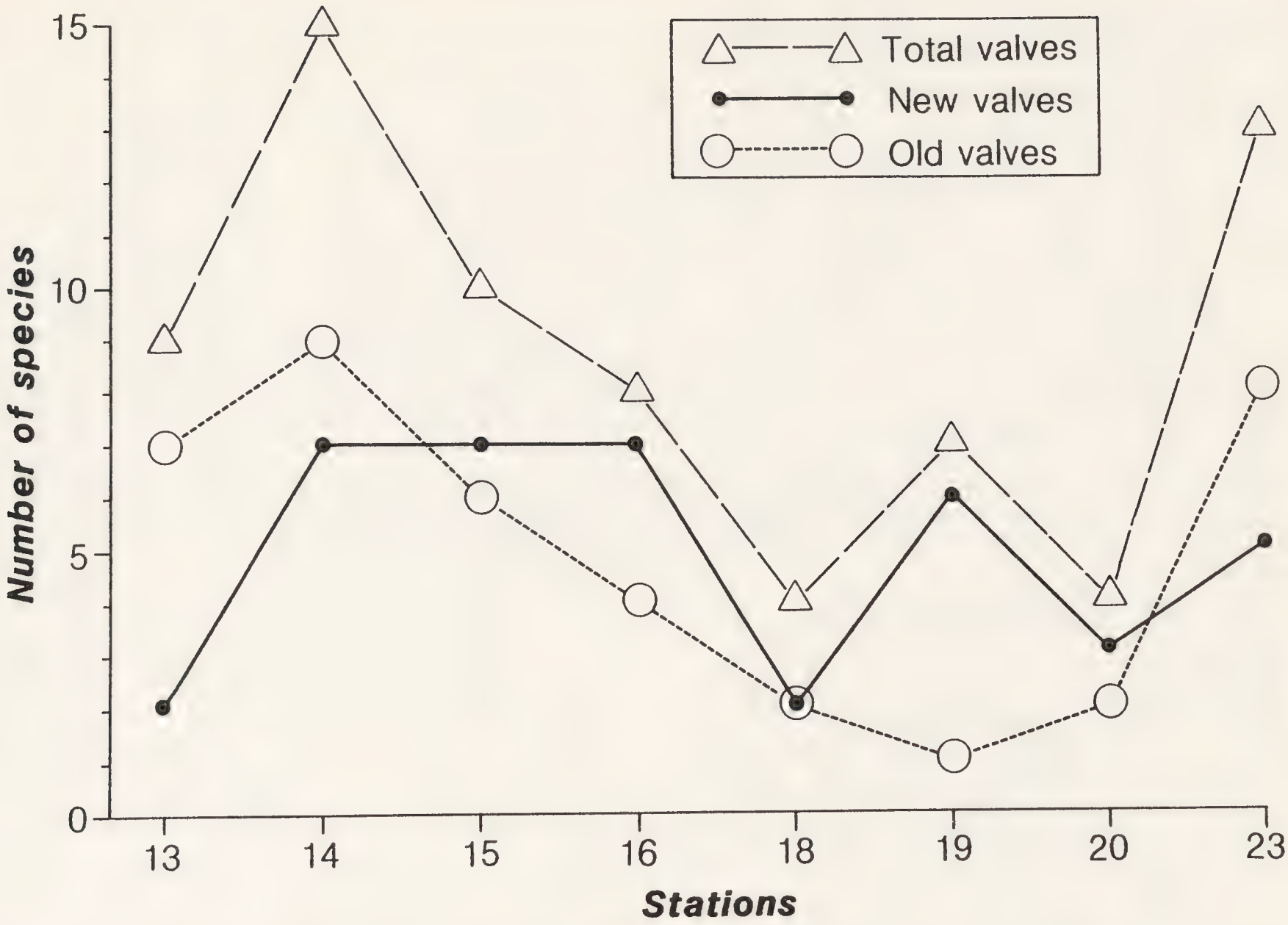

Fig. 3. Diversity of detrital mollusk shells.

ward ends of the transect (Fig. 2A), whereas new shells predominated at most sites in between. Too few shells were recovered at Stations 18 and 20 to depict a trend. New to old valve ratios (Fig. 2B) thus increased dramatically along the central part of the traverse.

The new:old ratio for total shells (1.27) was substantially less than ratios reported by Henderson and Frey (1986) from: (1) shallow sound sites off the southern end of Sapelo Island (7.36); (2) a longshore tidal channel immediately adjacent to the southeastern end of the beach (81.11); and (3) the nearshore shelf at the seaward end of the channel (where old shells were virtually absent). The difference in ratios indicates a substantially longer in-loco residence time for lower offshore shells than for nearshore shelf and sound shells. A corollary is the slow rate of deposition of offshore sediments relative to that of nearshore shelf and sound sediments (Howard and Reineck, 1972; Mayou and Howard, 1975).

Encrusting and Boring

Of the 125 specimens examined, 37% of new and 75% of old shells were invested with various combinations of borings and/or encrustations (Table 1). These associated organisms (or their lebensspuren) cannot be termed *epibionts* or *endobionts*, sensu stricto, because most were not coeval with the original, live mollusks; rather, the shells in most cases were utilized simply as rigid substrates (*cf.* Ekdale, 1985, p. 66, Fig. 1). In numerous specimens, both interior and exterior valve surfaces were occupied.

The most prevalent encrusters were several unidentified species of calcareous (chiefly cheilostome) bryozoans. Next most important were the calcareous tubes of various unidentified species of serpulid worms. Bivalve spat and acorn barnacles (Table 1) were substantially less common. Most of the tiny spat probably are referable to the bivalve *Anomia simplex*, although some possibly are referable to *Pododesmus rudis*. The barnacles included species of both *Balanus* and *Chathalmus* (rarely), and all individuals were small.

Among borings, the cavity networks of clionid sponges were predominant; these are equivalent to the trace fossil ichnogenus *Entobia* (Bromley, 1970; Brom-

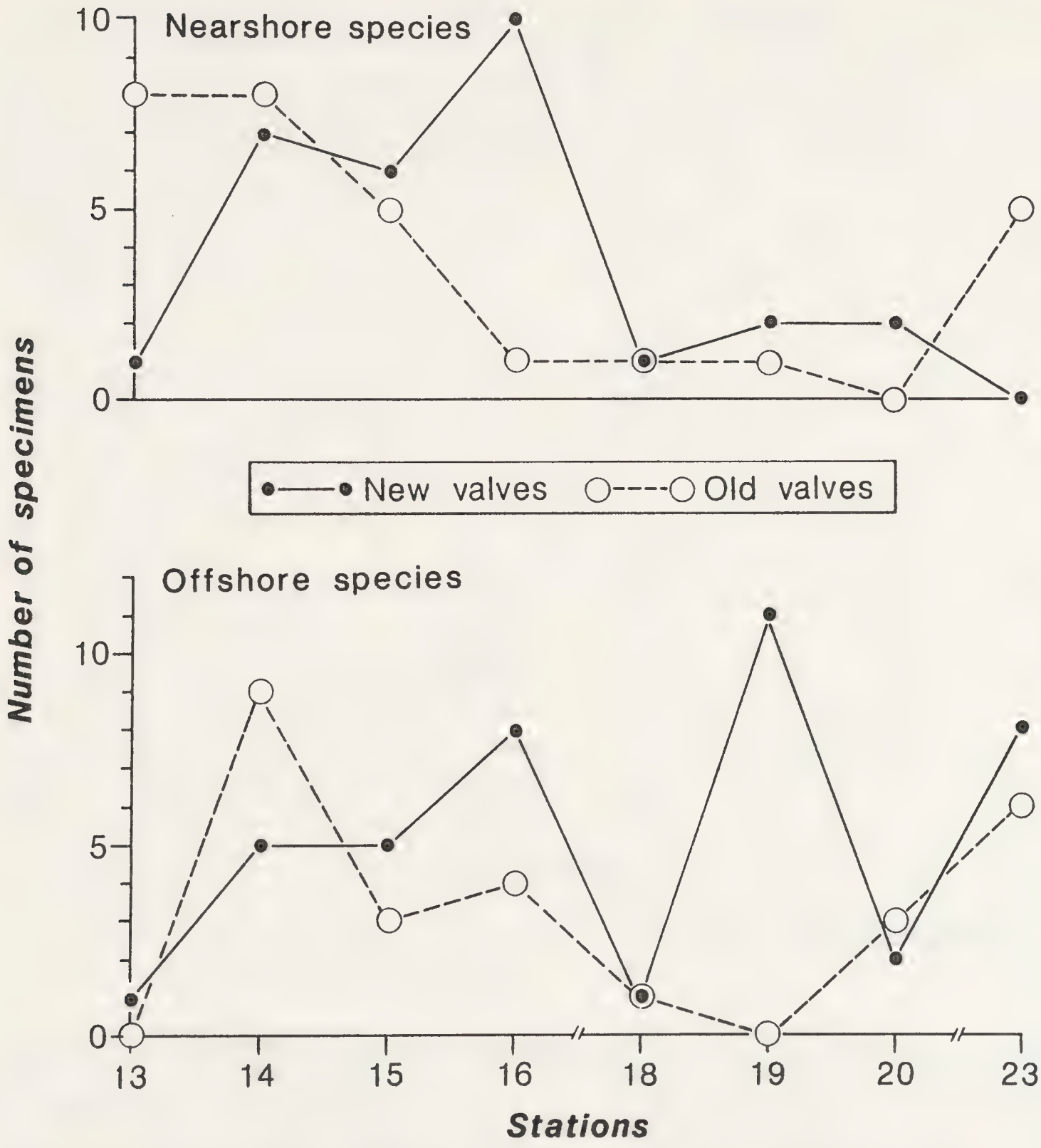

Fig. 4. Relative abundance of detrital mollusk shells with respect to inferred original environmental distribution.

ley and D'Alessandro, 1984). The small, slit-like excavations of acrothoracican barnacles, most of them equivalent to the ichnogenus *Rogerella* (Häntzschel, 1975), were common locally. Borings by gastrochaenid clams, referable to the ichnogenus *Gastrochaenolites* (Kelly and Bromley, 1984), included both small, pouch-like excavations in shells and well-cemented, agglutinated assessory tubes or "blisters" (*cf.* Warme, 1975, Fig. 11.25); several cavities still contained the valves of *Gastrochaena hians* (Appendix). No attempt was made to differentiate algal and fungal microborings (see Golubic *et al.*, 1975), which were common on some valves.

Boreholes made by predaceous gastropods, referable to the ichnogenus *Oichnus* (Bromley, 1981), were more common among new valves than among old valves (Table 1). Most of these holes were located in the umbonal region of bivalves; the style of penetration suggests that naticid gastropods such as *Polinices duplicatus* were responsible (see Carriker and Yochelson, 1968).

Altogether, the intensity of boring or encrustation is related more closely to the duration of shell exposure at the sediment-water interface than to the absolute age of the shell itself. One season of exposure to larval settling and metamorphosis is sufficient to initiate these processes, whether the host substrate is a recently dead Holocene or a long-buried but recently exhumed Pleistocene shell. On a probability basis, however, older shells are more apt to have been exposed longer or more often than newer shells. Thus, the fre-

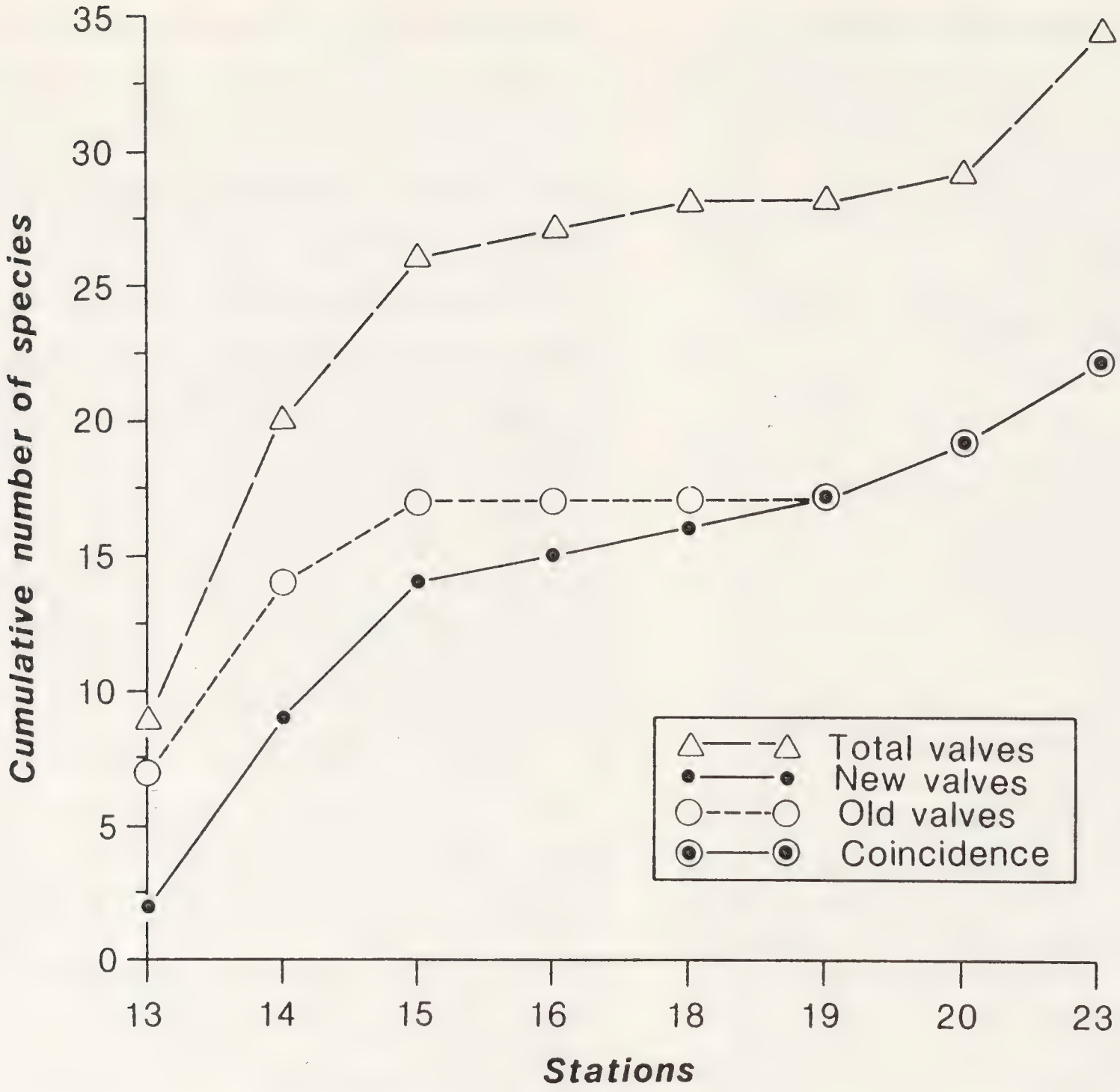

Fig. 5. Qualitative species-area curves for detrital mollusk shells.

quency and extent of boring and encrustation are general indicators of relative antiquity within the total assemblage (Table 1), but little reliance may be placed upon the temporal significance of any given specimen. A corollary mentioned previously is the slow rate of deposition on the offshore shelf in this area, which prolongs the in-loco exposure time for surficial shells.

Shell Diversity and Provenance

Altogether, shells of 10 species of gastropods and 24 species of bivalves were identified (Appendix). Shells of small species, such as those of the gastropod *Turbonilla*, probably were lost through the coarse mesh of the sieve (2.5 mm). Total diversity within the size fraction examined was substantially greater on the landward part than on the seaward part of the transect (Fig. 3), even though the assemblage at the seaward end (Station 23) was more diverse than those at closely adjacent sites. This trend was even more pronounced among old shells; species of new shells were somewhat more evenly distributed, especially considering the paucity of all shells at Stations 18 and 20 (Fig. 2A). These differences suggest that the newer shells represent relatively consistent, recent, penecontemporaneous conditions, whereas older valves reflect either a present or a previous environmental zonation (as during a lower stand of sea level; Rollins *et al.*, 1979) or subsequent redistribution and selective redeposition of relict shells by physical processes (*cf.* Pilkey *et al.*, 1978).

In further evaluation of these possibilities, shell assemblages may be divided into nearshore and offshore components (Pilkey *et al.*, 1969b). The following 16 species of shells have been reported from beaches and/or the nearshore shelf off Sapelo Island (Dörjes *et al.*, 1986; Hender-

son and Frey, 1986; Frey and Dörjes, in prep.), and hence may be considered as the nearshore component of the total assemblage (Appendix):

GASTROPODS
Crepidula fornicata
Diodora cayenensis
Oliva sayana
Polinices duplicatus
Terebra dislocata
BIVALVES
Anadara ovalis
Anadara transversa
Anomia simplex
Crassostrea virginica
Dinocardium robustum
Eucrassatella speciosa
Lucina pectinata
Lucina radians
Mulinia lateralis
Spisula solidissima similis
Strigilla mirabilis

Of these, *Diodora cayenensis*, *Eucrassatella speciosa*, *Lucina pectinata*, and *Lucina radians* are least common in nearshore or intertidal settings. The remaining 18 species (Appendix) are taken as the offshore component:

GASTROPODS
Cerithium atratum
Conus delessertii
Conus jaspideus stearnsi
Strombus alatus
Turritella acropora
BIVALVES
Arcinella cornuta
Argopecten gibbus
Chama congregata
Chione intapurpurea
Gastrochaena hians
Glycymeris undata
Laevicardium pictum
Linga pensylvanica
Macrocallista maculata
Macrocallista nimbosa
Pecten raveneli
Tellina aequistriata
Tellina listeri

All the above habitat assignments refer mainly to Georgia waters; latitudinal variations in habitat adaptations, and therefore in detrital shell distributions, are exhibited by some Atlantic-Gulf mollusk species (*cf.* Parker, 1960, 1969; Bird, 1970). By these criteria, the landward abundance of shells (Fig. 2A) is attributable to a mixture of offshore and nearshore components (Fig. 4), especially with respect to old valves. In contrast, the seaward end of the traverse is characterized by shells of offshore species. Equally important, these results show that old shells *per se* are not simply a relict suite of nearshore species (*cf.* Pilkey *et al.*, 1969b, p. 765); many specimens from the offshore component are equally "relict", or old-appearing. Nevertheless, new to old valve ratios are appreciably smaller among nearshore shells (0.97) than among offshore shells (1.58), reflecting a continuing dilution of the total assemblage by new offshore shells.

Trends depicted in Figure 4 further suggest predominantly in-loco shell accumulations along a crude environmental gradient rather than pronounced local concentrations of shells by physical processes. Even though some landward, physical displacement of shells may have occurred, the simplest explanation is that this area merely represents a transition between upper offshore and mid-shelf type shell deposits–the nearshore component being expressed best at the landward margin and the offshore component being developed best at the seaward margin of the zone.

This conclusion is supported to some extent by a qualitative species-area curve (Fig. 5), which also serves as a crude measure of sampling adequacy. "Plateaus" along the curves indicate that sampling was generally adequate through most of the transect, especially with regard to old shells (and to total shells, if no distinction is made between new and old valves); yet, the collections are only marginally representative of species diversity among new shells. Acceleration of the curves at Station 23 might be interpreted as sampling inadequacy; however, preliminary examinations of bulk assemblages from box cores taken farther offshore (Howard and Frey, 1980, Fig. 5) indicate a persistent, dramatic increase in abundance and diversity of middle- and outer-shelf shells per unit volume of sediment–attributable mainly to extremely slow rates of deposition there (except at the shelf-slope junction, where fine sediments are accumulating today) and the influence of the Gulf Stream (increased seaward diversification among benthos; Hanson *et al.*, 1981).

In short, the seaward end of the transect, which is three nautical miles from the nearest landward station (Fig. 1), is

deemed to be a normal part of the transition to conditions farther offshore and an integral part of the crude environmental gradient mentioned above. Abundance of nearshore shells evidently increases landward for the same reasons.

V. ACKNOWLEDGMENTS

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VII. APPENDIX

MOLLUSKS FROM OFFSHORE SHELF

Taxonomic checklist and summary of new and old valve distributions, detrital mollusk shells off Sapelo Island.

New/Old Mollusk Shells	Stations 13	14	15	16	18	19	20	23	Total
GASTROPODS									
Cerithium atratum (Born)	–	1/–	–	–	–	–	–	–	1/–
Crepidula fornicata (Linné)	–	–/2	–	–	–	–	–	–	–/2
Conus delessertii Récluz	–	–	–	–	–	–	–	1/–	1/–
Conus jaspideus stearnsi Conrad	–	–	–/1	–	–	–	–	–	–/1
Diodora cayenensis (Lamarck)	–/1	–	–	–	–	–	–	–	–/1
Oliva sayana Ravenel	–/1	1/–	–/1	2/1	–	–	–	–	3/3
Polinices duplicatus (Say)	1/–	–	–	–	–	–	–	–	1/–
Strombus alatus Gmelin	–	–	–	–	–	–	–	1/–	1/–
Terebra dislocata (Say)	–	–	1/–	3/–	–	1/–	–	–	5/–
Turritella acropora Dall	–	–	–	–	1/–	1/–	–	–	2/–
Total Gastropods	1/2	2/2	1/2	5/1	1/–	2/–	–	2/–	14/7
BIVALVES									
Anadara ovalis (Bruguière)	–/1	–	–	–	–	–	–	–	–/1
Anadara transversa (Say)	–/2	–	–	–	–	–/1	–	–	–/3
Anomia simplex Orbigny	–	4/–	2/–	5/–	–	–	2/–	–/1	13/1
Arcinella cornuta Conrad	1/–	–/2	–	1/1	–	2/–	–	–	4/3
Argopecten gibbus (Linné)	–	–	1/1	–/1	–/1	–	–	–/1	1/5
Chama congregata Conrad	–	–	–	1/–	–	–	–	3/–	4/–
Chione intapurpurea (Conrad)	–	–	2/1	3/2	–	6/–	–	–/3	11/6
Crassostrea virginica (Gmelin)	–	–	–	–	–	–	–	–/1	–/1
Dinocardium robustum (Lightfoot)	–	–/1	–	–	–	–	–	–	–/1
Eucrassatella speciosa (Adams)	–	–	–	–	–	–	–	–/1	–/1
Gastrochaena hians (Gmelin)	–	2/–	–	3/–	–	2/–	–	–	7/–
Glycymeris undata (Linné)	–	1/–	–	–	–	–	–	–	1/–
Laevicardium pictum (Ravenel)	–	–	2/–	–	–	–	–/2	2/–	4/2
Linga pensylvanica (Linné)	–	–/2	–	–	–	–	–	–	–/2
Lucina pectinata (Gmelin)	–/1	–	–	–	–	–	–	–	–/1
Lucina radians (Conrad)	–/1	–/2	–	–	–	1/–	–	–	1/3
Macrocallista maculata (Linné)	–	–/2	–	–	–	–	1/–	–/2	1/4
Macrocallista nimbosa (Lightfoot)	–	–/2	–	–	–	–	–	–	–/2
Mulinia lateralis (Say)	–	–	–/3	–	–	–	–	–/1	–/4
Pecten raveneli Dall	–	–	–	–	–	–	1/1	–	1/1
Spisula solidissima similis Say	–/1	2/3	2/1	–	–/1	–	–	–/1	4/7
Strigilla mirabilis (Philippi)	–	–	1/–	–	1/–	–	–	–	2/1
Tellina aequistriata Say	–	1/–	–	–	–	–	–	–	1/–
Tellina listeri Röding	–	–	–	–	–	–	–	1/–	1/–
Total Bivalves	1/6	10/15	10/6	13/4	1/2	11/1	4/3	6/11	56/48
Total Mollusks	2/8	12/17	11/8	18/5	2/2	13/1	4/3	8/11	70/55

REVIEW

beginnings of the planet Earth, its sister planets, and the Sun, as well as the emergence of life upon Earth.

In Contributions of Individuals, Robert Dott describes James Hall's Discovery of the Craton and recognition of the fundamental difference between the central plate and the bordering orogenic belts, emphasizing that Hall himself was much more interested in acquiring and describing fossils and extending our knowledge of stratigraphy than in publishing his mountain building theory; George Merk reviews the controversial concepts of E. O. Ulrich which supported and fostered the Wernerian "onion peel" or "layer-cake" geology in America during the first three decades of the twentieth century even though the concept that stratigraphic and faunal units normally end in a facies change was in common usage in Europe at the time. Additional essays deal with the pioneer geologist J. A. Udden and his research on wind-blown sediments that led to the particle distribution scheme used by modern sedimentologists, the Udden-Wentworth scale; R. S. Tarr, one of the pioneers of glacial geology and physical geography who devoted his brief professional life to the study of ice masses and the effects that they have had on the landscape; L. R. Wager and the Geology of East Greenland; Dr. Atl, Pioneer Mexican Volcanologist and muralist; and, Joseph A. Cushman and the Study of Foraminifera, including a review of his life work on the description and classification of these organisms which have had such a profound effect on subsurface geology and correlation, and of the famed controversy with J. J. Galloway over the publication of their respective classifications. The last paper in this section, Wrong for the Right Reasons: G. G. Simpson and Continental Drift describes the opposition to Continental Drift of this pre-eminent geologist who was wrong about Continental Drift and used his own historical biogeography based on Cenozoic mammals to refute the theory.

The third section, *Contributions of Organized Groups*, begins with Surveying the Geology of a Vast, Empty, Cold Country, the enormous task of taking inventory of Canada's minerals, rocks, and fossils, so overwhelming that "numberless difficulties inherent in such an undertaking, embracing a range of country so vast and so difficult to explore, or even to obtain access to, must necessarily render any attempt of this nature very imperfect" (Isbister, 1855). The geological description of the second largest country on Earth (nearly ten million square kilometers) began with the establishment in 1842 of the Geological Survey of Canada, headed by William Edmund Logan. The early work began with travel by canoe or on foot under conditions arduous at best and confronted a vast and empty hinterland so sparsely populated that no more than 100,000 indigenous persons dwelt there. Even today, more than 20 of Canada's 24 million people live within a narrow southern strip bordering the United States and extending along its maritime provinces. McGill College, founded at Montreal in 1821 by Royal Charter, became McGill University in 1843. John William Dawson became its head in 1855 and remained for 38 years, never yielding from his fundamentalist views on the origin nor from his opposition to the theories of organic evolution and continental glaciation. He exerted enormous influence on early Canadian science. That so much scientific progress took place during the nineteenth century is an everlasting tribute to the stalwart pioneers of Canadian geological investigation. Other papers in this section are concerned with the Contributions of the State Geological Surveys (many founded by the students of Benjamin Silliman); the Role and Development of the Smithsonian Institution in the American Geological Community, the unsurpassed contributions of both the institution and its personnel (so ably recounted by Ellis Yochelson); A Brief History of the Geological Sciences at Yale, beginning with the appointment of Benjamin Silliman as Professor of Chemistry and Natural History in 1802, continuing with James Dwight Dana (1850) and through five more generation-long stages (the seventh and last beginning in 1965); and, A History of Geology at the University of Pennsylvania, from the early ruminations on diverse geological and geophysical matters by Benjamin Franklin, John Bartram, Benjamin Smith

(Continued on p. 90)

AN EVALUATION OF THE TAXA *MURICOPSIS* AND *RISOMUREX* (GASTROPODA: MURICIDAE), WITH ONE NEW SPECIES OF *RISOMUREX*

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I. ABSTRACT

Risomurex is considered to be a subgenus of *Muricopsis*, being distinguished from the latter by lacking true varices, having instead only rounded axial ridges. All species are in the Atlantic Ocean with the majority found in the tropical western Atlantic; three are from West Africa; one is from temperate South America. One fossil species, presumed to be the ancestral form, occurs in the Burdigalian of France and Florida. The habitat of all is extremely shallow water, under rocks or coral boulders, the deepest known occurrence is no more than 30 m (for *roseus*) but most are intertidal. All are small; the largest (*necocheanus* and *gilbertharrisi*) are under 25 mm in height and most are about 15 mm. In all, there are 11 species recognized: two fossil forms; one Pliocene-Recent form; the remaining all Recent, of which one is a new species, *M. (R.) withrowi*, described from northern South America.

II. INTRODUCTION

Olsson and McGinty (1958, p. 40) originally described the muricid genus *Risomurex* without any comparison to the similar *Muricopsis* Bucquoy and Dautzenberg, 1882. As the authors noted, "Caribbean species of this group have been referred to *Ocenebra, Engina, Ricinula*, and most recently to *Ocinebrina*." They included in their new taxon four species: "*Engina*" *schrammi* Crosse, 1863 (the type); "*Fusus*" *muricoides* C. B. Adams, 1845; "*Ricinula*" *rosea* Reeve, 1846; and "*Murex*" *alveatus* Kiener, 1842. They added that the radula of *R. schrammi* is very close to that of "*M.*" *alveatus*, which is true, as both *Risomurex* and *Favartia*, to which *alveatus* is more correctly assigned (as subgenus *Caribiella*), are now placed in the subfamily Muricop-

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sinae, characterized by having a three-dimensional rachidian tooth.

The only taxon with which Olsson and McGinty compared *Risomurex* was the Mediterranean *Ocinebrina*, no doubt due to Bartsch and Rehder's placement of their "*Tritonalia*" *caribbaea* in the subgenus *Ocinebrina*, and Abbott's (1954, p. 44) subsequent transfer of that species to synonymy with what he then termed "*Ocenebra (Ocinebrina) muricoides* (Adams)."

There is a superficial resemblance between *Ocinebrina* Jousseaume and *Risomurex*, in that both have non-varicate shells, with heavily denticulated apertures. However, this is due to convergence and *Ocinebrina*, as Abbott indicated, is a subgenus of *Ocenebra*, placed in the subfamily Ocenebrinae. The latter is distinguished by having calcitic (not aragonitic) shells, purpuroid opercula, thaid radulae, and (usually) a sealed siphonal canal.

In addition to *Ocinebrina*, the members of this group have been placed in a variety of muricid, thaid, and even buccinid genera. The latter usually has been *Engina* Gray, 1847 (type species: *E. zonata* Gray), superficially similar with its biconic, non-varicate shell and denticulated aperture. But, in addition to the buccinid radula, the two shell forms may be distinguished by the series of small denticles extending along the entire length of the columellar lip in *Engina*.

Initially most species were described as "*Ricinula*" or "*Sistrum*," both of which are synonyms of *Drupa* Röding, 1798 (type species: *D. morum* Röding), a thaid genus with numerous accessory denticles on the rachidian tooth and a purpuroid operculum. However, at the time of this usage, species now referred to *Morula* Schumacher, 1817 (type species: *Morula papillosa* Schumacher, 1817, = *Drupa uva* Röding, 1798) were also included in *Drupa* s.l., and there is a stronger resemblance between these forms and those here placed in *Risomurex*.

The genus *Morula*, which is Indo-Pacific in distribution, includes a group of species that have heavily denticulated apertures and non-varicate shells with nodulose axial sculpture. Although resembling members of *Drupa* in shell from, especially in the conspicuous purple aperture, the radula of the group is muricine, as is the operculum. *Morula* differs from *Risomurex* in the nature of the radula (muricine not muricopsine), in the arrangement of the labral denticles, and in having a strong plait in the center of the columellar wall, just opposite the largest of the labral denticles, greatly constricting the apertural opening.

In 1971 Vokes considered the genus *Risomurex* as being in the thaid family, somewhere near *Drupa*, and did not include the species in her "Catalogue of the genus *Murex*." But, in 1976, Radwin and D'Attilio observed that the radula, shell, and protoconch of the three species of *Risomurex* are muricid, nearly identical to the genus *Muricopsis*, and they synonymized the two taxa. Their illustration of the radula of "*M. schrammi*" (= *M. deformis*) (1976, fig. 112) shows the characteristic three-dimensional rachidian tooth of the subfamily. For the radula of "*Risomurex roseus*," unfortunately they illustrated some ocenebrine species, perhaps *Trachypollia nodulosa* (Adams, 1845) (compare Radwin and D'Attilio, 1976, fig. 110, with the same authors, 1972, fig. 11).

Although we are in complete agreement that *Risomurex* is closely allied with *Muricopsis*, the non-varicate shell of *Risomurex*, in contrast to the varicate shell of *Muricopsis*, seems sufficient justification for separating the two* at the subgeneric level (compare pl. 2, fig. 11 with others). This decision is further strengthened by the discovery of two additional *Risomurex* species, one of which is described below, that are in turn closely related to a fossil form described from the Miocene of France as "*Jania*" *crassicosta* Benoist,

*This same conclusion was reached independently by Kemperman and Coomans (1984), in a paper that appeared as ours was nearing completion. Their conclusions are essentially in agreement with ours (considerably blunting the impact of our paper), their most important contribution being the observation that the shell usually considered to be *M. (R.) schrammi* by all authors since Olsson and McGinty is not that form but another, which they named as a new species. In our opinion, the species in question is *M. (R.) deformis* (Reeve), which they state is similar to their new species but not the same.

1873, but which also occurs in the Early Miocene Chipola Formation of northwestern Florida (see pl. 3, figs. 6, 7). Although described in the buccinid genus *Jania*, the French species is unquestionably a *Risomurex*, the earliest member of the line yet discovered. Thus, the group has had a long geologic history of being distinct from *Muricopsis*, which first appears in the Middle Eocene of California (*Muricopsis vistaensis* Givens and Kennedy, 1976).

We agree with Olsson and McGinty (1958) and Kemperman and Coomans (1984) as to the species included in this subgenus [excluding "*M.*" *alveatus*, which as noted above is better referred to *Favartia (Caribiella)* and is perhaps better known to readers as *Murex intermedius* C. B. Adams, 1850, *non M. intermedius* Brocchi, 1814.] What there is not agreement on is the name by which these species are to be called. The nomenclature of the entire group is unusually complicated not only at the generic level but also at the species level.

Our studies show there are eleven species that may be assigned to the subgenus *Risomurex*. These are:

1. *deformis* (Reeve) (=*schrammi* of authors; =*mosquitensis* Kemperman and Coomans, 1984). Occurring only along the coast of Caribbean Central America, from the Chinchorro Banks, Mexico, to Panamá; a single dead specimen reported from the north coast of Cuba.
2. *roseus* (Reeve) (of which *schrammi* Crosse is probably a synonym). Found throughout the Antilles and the northeasternmost coast of Venezuela (Sucre State).
3. *caribbaeus* (Bartsch and Rehder) (=*Fusus muricoides* Adams, 1845, *non F. muricoides* Deshayes, 1835). The most widespread of the species, occurring from the Florida Keys to Barbados, and through the Caribbean from Yucatan to Panamá; however, not known from the northern coast of South America, except one island off Venezuela.
4. *gilbertharrisi* (Weisbord). Venezuela only; Late Pliocene near Caracas and living only in vicinity of Isla de Margarita.
5. *withrowi* Vokes and Houart, n. sp. From northern coast of South America (Colombia and Venezuela), Trinidad, Tobago, and Netherlands Antilles.
6. *rutilus* (Reeve). Ghana, West Africa.
7. *fusiformis* (Gmelin). Sénégal, West Africa.
8. *suga* (Fischer-Piette). Sénégal, West Africa.
9. *galbensis* (Jung). Early Pliocene of Trinidad.
10. *necocheanus* (Pilsbry). The only temperate species, found from central Brazil to northern Argentina.
11. *crassicosta* (Benoist). Early Miocene (Burdigalian) of France and Florida.

III. ACKNOWLEDGMENTS

The main framework of this paper is based upon work done at the British Museum (Natural History) and the Muséum National d'Histoire Naturelle, Paris, and to the members of the molluscan sections of these two institutions: John D. Taylor and Kathie Way, of the first; and Philippe Bouchet and J. E. Pointier, of the second, we extend our deepest gratitude for the multitude of favors rendered. In addition, this paper has required more than the usual amount of borrowing of specimens and seeking of information. For all of this help we wish to acknowledge our indebtedness to the following persons: the late Joseph Rosewater and Thomas R. Waller, U. S. National Museum; Ruth D. Turner and David H. Backus, Harvard Museum of Comparative Zoology; Peter Hoover, Paleontological Research Institution; Mary A. Garback, Academy of Natural Sciences, Philadephia; William K. Emerson, American Museum of Natural History; H. E. Coomans, Zoologisch Museum, Universiteit van Amsterdam; D. L. N. Vink, Wassenaar, Netherlands; R. von Cosel; Geissen, Germany; Emilio García, Lafayette, Louisiana; David G. Robinson, New Orleans, Louisiana; Robert Foster, Santa Barbara, Californa; Pierre Lozouet, Morigny, France; Emilio Rolán, Vigo (Pontevedra), Spain; and Peter Ryall, Takoradi, Ghana. In particular, for South American material, Mr. and Mrs. J. Gibson-Smith, Caracas, Venezuela, made available their extensive collection, permitting us to determine the distributional

extent of many of the species for the first time.

IV. SYSTEMATIC DESCRIPTIONS

Family MURICIDAE Rafinesque, 1815
Subfamily MURICOPSINAE Radwin and D'Attilio, 1972
Genus MURICOPSIS Bucquoy and Dautzenberg

Muricopsis BUCQUOY and DAUTZENBERG, *in* BUCQUOY, DAUTZENBERG, and DOLLFUS, 1882, Moll. Mar. Roussillon, v. 1, p. 19.

Type species: Murex blainvillei Payraudeau, 1826, by original designation.

Subgenus RISOMUREX Olsson and McGinty

Risomurex OLSSON and MCGINTY, 1958, Bulls. Amer. Paleontology, v. 39, no. 177, p. 40.

Type species: Engina schrammi Crosse, 1863, by original designation.

MURICOPSIS (RISOMUREX) DEFORMIS (Reeve)
Plate 2, figs. 1-5

Ricinula deformis REEVE, 1846 [plate dated "1856" in error], Conch. Icon., v. 3, *Ricinula*, pl. 6, fig. 44.

Engina deformis (Reeve). TRYON, 1883, Man. Conch., v. 5, p. 192, pl. 62, fig. 37.

Sistrum ferrugineum [sic] rubidum DALL, 1889, Harvard Mus. Comp. Zool., Bull., v. 18 ("Blake" Rept.), p. 217.

Sistrum ferrugineum [sic] rubidum Dall. M. SMITH, 1953, Illus. Cat. Recent Spec. Rock Shells, p. 30.

Risomurex schrammi (Crosse). OLSSON and MCGINTY, 1958, Bulls. Amer. Paleontology, v. 39, no. 177, p. 41, pl. 2, figs. 2, 2a (*not* of Crosse).

Risomurex roseus (Reeve). WARMKE and ABBOTT, 1961, Caribbean Seashells, p. 106, pl. 19b (*not* of Reeve).

Ocenebra (Risomurex) schrammi (Crosse). ABBOTT, 1974, American Seashells, p. 184 (*not* of Crosse).

Muricopsis schrammi (Crosse). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 171, pl. 2, fig. 1, text fig. 111 (protoconch-worn), 112 (radula) (*not* of Crosse).

Risomurex schrammi (Crosse). KAICHER, 1979, Card Cat. World Wide Shells, pack no. 20 (Muricidae IV), no. 2010 (*not* of Crosse).

Risomurex deformis (Reeve). KEMPERMAN and COOMANS, 1984, Zool. Mus. Univ. Amsterdam, Bull., v. 10, no. 1, p. 5, fig. 5 (holotype).

Risomurex mosquitensis KEMPERMAN and COOMANS, 1984, Zool. Mus. Univ. Amsterdam, Bull., v. 10, no. 1, p. 1, figs. 3, 4.

Risomurex schrammi (Crosse). SARASÚA and ESPINOSA, 1984, Poeyana, no. 273, p. 3, fig. 5A (*not* of Crosse).

Description: Shell of average size for the subgenus, height to 15 mm; roundly fusiform and solid. Aperture ovate and narrow; columellar lip adherent to shell on its whole surface, two elongate denticles on anterior part; anal notch fairly deep and strong; outer apertural lip weakly crenulate, inner side with five heavy, slightly elongate denticles, the second being stronger and more than twice as large as the others. Spire high; protoconch of one and one-half keeled whorls; five rounded postnuclear whorls. Suture slightly impressed. Body whorl with eight or nine rounded axial ridges; apertural varix bearing five short spines. Spiral sculpture consisting of eight or nine major cords; one or two on the shoulder, five on the body and two weaker on the siphonal canal; small nodes developed at the intersection of spiral cords and axial ribs, giving a nodulose appearance to the shell; other spiral sculpture consisting of two or three intermediate, somewhat squamose threads between each pair of cords. Siphonal canal short, straight and narrowly open. Color light to dark brown with white, cream, or light pink nodes where the spiral cords cross the axial sculpture; protoconch and first two spire whorls pink; aperture bluish-white, surrounded with light brown.

Holotype: BMNH 196872.

Dimensions of holotype: Height 8.8 mm, diameter 5.8 mm.

Type locality: TU R-366, Punta Cahuita, Costa Rica (here designated).

Figured specimens: Fig. 1, BMNH 196872 (holotype). Fig. 2, USNM 820637, height 12.0 mm, diameter 8.2 mm; locality TU R-366. Fig. 3, USNM 820638, height 14.7 mm, diameter 8.7 mm; locality TU R-109. Fig. 4, USNM 61199 (holotype-*Sistrum rubidum* Dall); height 8.6 mm, diameter 6.5 mm; locality, Utila, Bay Islands, Honduras. Fig. 5, ZMA 384001 (holotype-*Risomurex mosquitensis* Kemperman and Coomans); height 11.7 mm, diameter 6.9 mm; locality, Puerto Vargas, Costa Rica.

Discussion: Tryon (1883, p. 192) was the first author to consider the members of *Risomurex* as a group, assigning them to the genus "*Engina*." He placed *E. schrammi* Crosse in synonymy with *Ricinula rosea* Reeve and added that *Ricinula deformis* Reeve was probably also a synonym.

The species were only fleetingly men-

tioned by Dall in the *Blake* Report (1889, p. 217), where he noted that they should be referred to the genus *Sistrum* and added that the Caribbean species included "*S. roseum* Reeve, . . . *Sistrum nodulosum* C. B. Adams, [and] *S. ferrugineum [sic]* Reeve, a beautiful variety of which has the spiral nodules small, elongated, and scarlet, while the rest of the surface is a dark vernicose brown. The columella in this form is also a fine red color, and it seems worthy of separation as a variety *rubidum.*"

The name "*Ricinula ferruginosa** Reeve" has been used for years for a species from the eastern Pacific, but the type specimens prove to be the Atlantic *Trachypollia nodulosa* (Adams) (see Vokes, 1984, for further discussion). However, the scarlet "variety" to which Dall gave the name "*rubidum*" is a different form that already had the name *Ricinula deformis*.

When Olsson and McGinty (1958) did their study of the group and named the taxon *Risomurex* they overlooked both *deformis* and *rubidum*, naming what they considered to be "*schrammi* Crosse" type of their new genus. Although "*Ricinula*" *deformis* was described without locality data, the illustration is accurate and it is curious that this name has been completely overlooked in the past. The taxon was so obviously pertinent to the study of *Risomurex* that a special effort was made to examine the type of Reeve's species in the British Museum. One glance was sufficient to realize it is the form, common along the Caribbean coast of Panamá and Costa Rica, which Olsson and McGinty cited as "*R. schrammi.*"

Thus, it was very surprising to see the recent paper by Kemperman and Coomans in which they described this form as a new species, *R. mosquitensis*. Had they not been aware of Reeve's name it would be understandable, but they figured Reeve's type and stated that it "resembles beachworn specimens of *Risomurex mosquitensis* . . . [but] the whorls are more globose than those of *R. mosquitensis*" (1984, p. 5). Having in our collections dozens of specimens of *M. (R.) deformis*, we cannot see the validity of their statement and the two are considered as synonymous. Furthermore, even if they did not believe *M. deformis* to be the correct name for the form, Dall's "*Sistrum ferrugineum rubidum*" is available. Although they consider the name to be a *nomen dubium*, "since no type material is known, no type locality is given and the poor description makes identification impossible" (*ibid.*, p. 5), we cannot accept any of these arguments. In the first place, the description is completely unequivocal and could not be referring to any other species; but what is even more important, there is a type specimen in the collections of the U. S. National Museum, labeled as coming from "Utilla Id. [Utila, one of the Bay Islands], Honduras." Although it is a poor specimen, covered at both the apex and the canal by encrusting foraminifera there is no doubt as to its identity, as may be seen in pl. 2, fig. 4.

The type specimen of "*R.*"*deformis* (figured here, pl. 2, fig. 1), as noted by Reeve (1846, expl. pl. 6), is "characterized by the depressed obesity of the spire," which is a result of the apex being broken in life and replugged by the animal. This is a fairly normal occurrence among the numerous examples in the Tulane collections from TU R-366, Punta Cahuita, Costa Rica, where the species is found in large numbers (see pl. 2, fig. 2). As Reeve gave no locality, Pta, Cahuita is here designated as type locality for "*Ricinula*" *deformis*.

Although the species bears some resemblance to the original illustration of "*Engina*" *schrammi*, as shown by Kemperman and Coomans, who figured the drawing and the type specimen (*ibid.*, figs. 6, 7), there is not a great deal of similarity beyond the generic level. The designation of "*E.*" *schrammi* as type species of *Risomurex* by Olsson and McGinty presents a problem that may be resolved in three different ways. According to the *Code of Zoological Nomenclature* (Art. 70a), if the type species of a genus is considered to have been misidentified, a petition should be made to the Commission to designate either: (1) the nominal species actually involved; *i.e.*, *R. deformis*; (2) a

*The misspelling "*ferruginea,*" which appears repeatedly in the literature, seems to have originated with Tryon, 1880, p. 190 and expl. to pl. 59 (although correctly spelled on p. 233).

species chosen in conformity with the usage of the generic name at the time the misidentification is discovered; or (3) the species named by the designator, regardless of the misidentification, *i.e.*, *E. schrammi*.

Kemperman and Coomans have indicated that they intend to recommend solution no. 1 in their petition and ask to have *R. mosquitensis* declared type but this will simply introduce further problems, as *R. mosquitensis* is a subjective synonym of both *M. (R.) deformis* and *M. (R.) rubidus* (Dall). If the third alternative is selected, leaving *E. schrammi* as type, this also invites problems, with *E. schrammi* being a subjective synonym of *M. (R.) roseus* (Reeve). It seems the most desirable course to designate *M. deformis* itself and remove any possible confusion.

This small species is more widespread than indicated by Kemperman and Coomans (*ibid.*, fig. 1), and is moderately common, usually occurring on the undersides of coral slabs in shallow water. In the Tulane Collections there are numerous examples not only from Panamá and Costa Rica, but also from the Bay Islands, off Honduras, and to as far north as the Chinchorro Banks, Quintana Roo, Mexico (collected by Emilio García, subsequent to the publication of Vokes and Vokes, 1983). We know of no records from the Antilles except Sarasúa and Espinosa (1984, p. 3), who have reported a single dead specimen collected in sand dredged from the beach at La Habana, Cuba. Warmke and Abbott (1961, pl. 19b) figured it (as "*R. roseus*") from the "West Indies" but they gave no exact location. Likewise, there are no specimens known from the northern part of South America (Gibson-Smith, *in litt.*, 5 Jan. 1985). It would seem that *M. deformis* and *M. roseus* do not occur in the same area, with *M. deformis* being confined to the Central American coast and *M. roseus* to northern South America and the Antilles.

MURICOPSIS (RISOMUREX) ROSEUS (Reeve)
Plate 1, figs. 5-9

Ricinula rosea REEVE, 1846 [plate dated "1856" in error], Conch. Icon., v. 3, *Ricinula*, pl. 6, fig. 46.

Engina rosea (Reeve). TRYON, 1883, Man. Conch., v. 5, p. 192, pl. 62, fig. 34.

Sistrum roseum (Reeve). DALL, 1889, Harvard Mus. Comp. Zool., Bull., v. 18 ("Blake" Rept.), p. 217.

Sistrum roseum (Reeve). JUAME and SARASÚA, 1943, Soc. Malac. "Carlos de la

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PLATE 1

Figures

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1. *Muricopsis (Risomurex) schrammi* (Crosse) 76
(X5) Coll. J. de C., Mus. Natl. Hist. Nat., Paris (holotype); height 8.8 mm; diameter 5.5 mm.
Locality: Guadeloupe, French Antilles, (Fig. 1c whitened)
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2. (X 4) BMNH 1968461 (lectotype); height 12.0 mm, diameter 5.5 mm.
Locality: Unknown.
3. (X4) Houart Coll.; height 13.0 mm, diameter 6.2 mm.
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Locality: "Island of Masbate."
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Locality: Unknown.
7. (X4) García Coll.; height 10.9 mm, diameter 6.2 mm.
8. (X4) García Coll.; height 9.5 mm, diameter 5.0 mm.
Locality of both: Shell Beach, Antigua, B.W.I.
9. (X4) Robinson Coll.; height 11.5 mm, diameter 6.4 mm.
Locality: Punta Rucia, Prov. Puerto Plata, Dom. Rep. (Whitened)

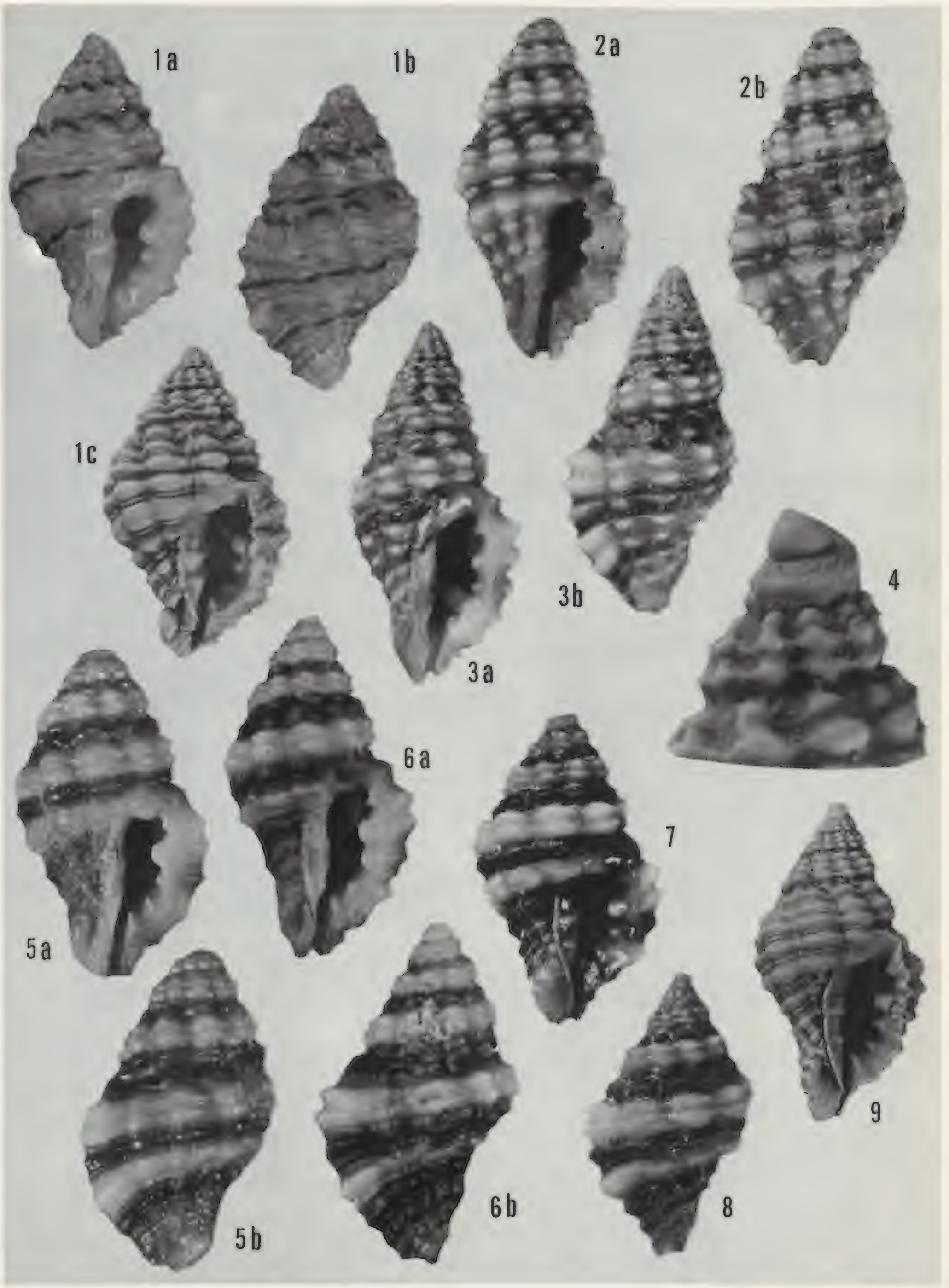

PLATE 1

Torre," Rev., v. 1, no. 2, p. 59.

Sistrum roseum (Reeve). M. SMITH, 1953, Illus. Cat. Recent Spec. Rock Shells, p. 31, pl. 20, figs. 1.

Risomurex roseus (Reeve). OLSSON and MCGINTY, 1958, Bulls. Amer. Paleontology, v. 39, no. 117, p. 41.

Not *Risomurex roseus* (Reeve). WARMKE and ABBOTT, 1961, Caribbean Seashells, p. 106, pl. 19b (=*M. deformis* Reeve).

Not *Risomurex roseus* (Reeve). GIBSON-SMITH and GIBSON-SMITH, 1972, VI Conf. Geol. Caribe, p. 474 (=*M. withrowi* n. sp.).

Ocenebra (Risomurex) rosea (Reeve). ABBOTT, 1974, American Seashells, p. 184.

Risomurex roseus (Reeve). HUMFREY, 1975, Sea Shells of the West Indies, p. 139, pl. 16, fig. 11.

Muricopsis roseus (Reeve). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 170, pl.2, fig. 5, text fig. 109 (protoconch), *not* text fig. 110 (radula of *Trachypollia nodulosa?)*.

Morula rosea (Reeve). CERNOHORSKY, 1978, Rec. Auckland Inst. Mus., v. 15, p. 76, fig. 23 (syntype BMNH 1968458).

Risomurex roseus (Reeve). KAICHER, 1979, Card Cat. World Wide Shells, pack no. 20 (Muricidae IV), no. 1996.

Not *Morula rosea* (Reeve). KAICHER, 1980, Card Cat. World Wide Shells, pack no. 25 (Muricidae V), no. 2447 (= *?Ergalatax bicatenatus* Reeve).

Muricopsis roseus (Reeve). POINTIER, ERAVILLE, and DELPLANQUE, 1982, Xenophora, no. 9, p. 9.

Risomurex rutilus (Reeve). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (MARI Publ. 54), p. 24 (*not* of Reeve).

Risomurex roseus (Reeve). KEMPERMAN and

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1-5. *Muricopsis (Risomurex) deformis* (Reeve) 66

1. (X5) BMNH 196872 (holotype); height 8.8 mm, diameter 5.8 mm.
   Locality: Unknown.
2. (X4) USNM 820637; height 12.0 mm, diameter 8.2 mm.
   Locality: TU R-366.
3. (X3-1/2) USNM 820638; height 14.7 mm, diameter 8.7 mm.
   Locality: TU R-109.
4. (X5) USNM 61199 (holotype-*Sistrum rubidum* Dall); height 8.6 mm, diameter 6.5 mm.
   Locality: Utila, Bay Islands, Honduras.
5. (X4) ZMA 384001 (holotype-*Risomurex mosquitensis* Kemperman and Coomans); height 11.7 mm, diameter 6.9 mm.
   Locality: Puerto Vargas, Costa Rica. (Photograph courtesy of Zoology Museum Amsterdam)

6. *Muricopsis (Risomurex) galbensis* (Jung) 83
   (X3-1/2) USNM 645367 (holotype); height 13.8 mm, diameter 7.7 mm.
   Locality: Pt. Courbaril, Trinidad; Courbaril Sand Member, Morne l'Enfer Fm. (Whitened)

7-9. *Muricopsis (Risomurex) caribbaeus* (Bartsch and Rehder) 77

7. (X3) MCZ 186097 (holotype-*Fusus muricoides* C. B. Adams); height 15.3 mm, diameter 7.1 mm.
   Locality: Jamaica.
8. (X3) USNM 820639; height 13.9 mm, diameter 7.0 mm.
   Locality: TU-R-389, Monte Cristi, Dom. Rep. (Whitened)
9. (X6) USNM 472617 (holotype-*Tritonalia caribbaea* Bartsch and Rehder); height 8.3 mm, diameter 4.0 mm.
   Locality: Isla de Providencia, Colombia.

10. *Muricopsis (?Risomurex) necocheanus* (Pilsbry) 84
    (X3) Vokes Coll.; height 19.4 mm, diameter 9.8 mm.
    Locality: Cabo Frio, Brazil. (Fig. 10a whitened)

11. *Muricopsis (Muricopsis) blainvillei* (Payraudeau) 64
    (X2-1/2) Vokes Coll.; height 22.1 mm, diameter 10.8 mm.
    Locality: Cartagena, Spain. (Whitened)

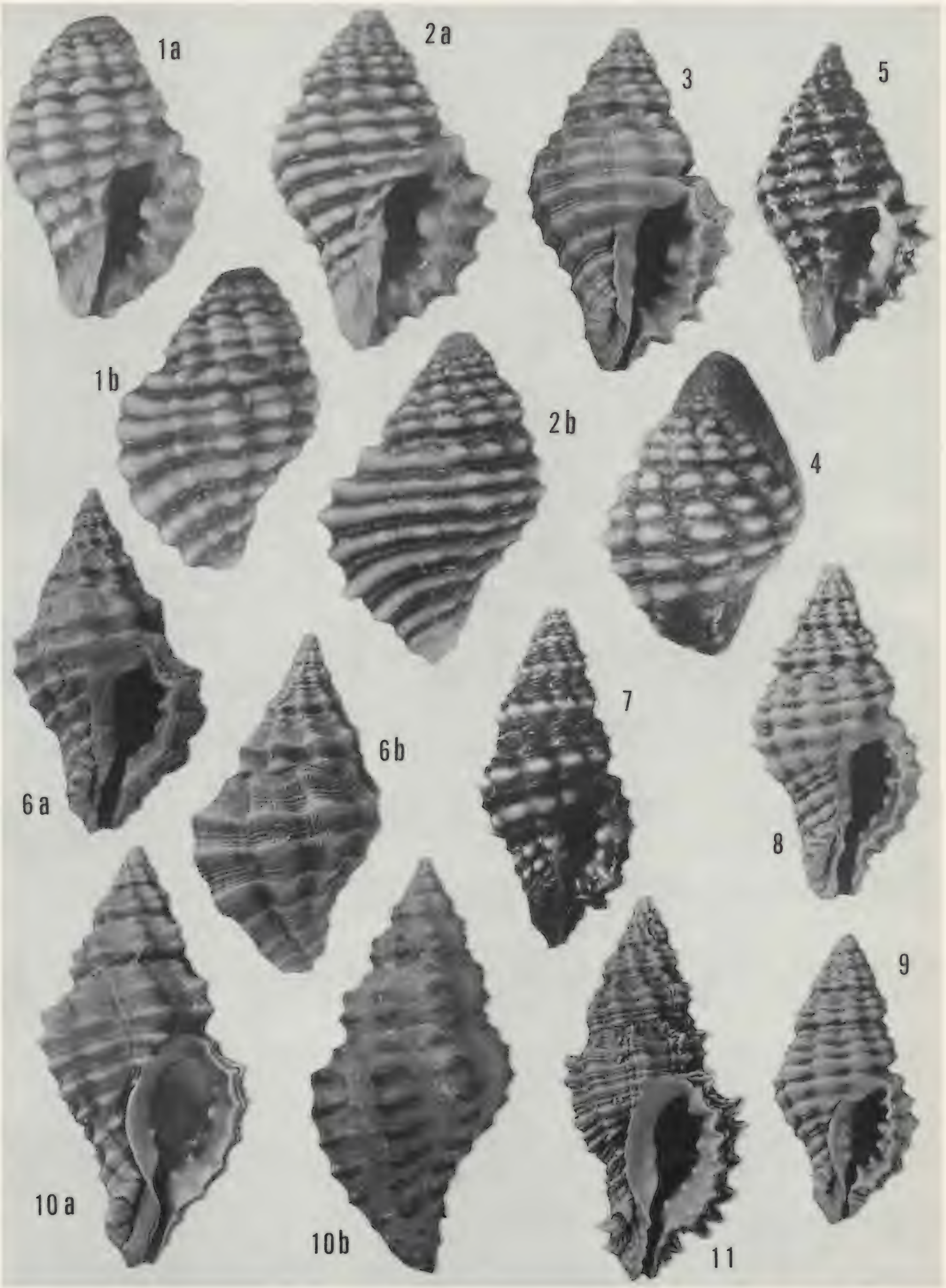

PLATE 2

COOMANS, 1984, Zool. Mus. Univ. Amsterdam, Bull., v. 10, no. 1, p. 5, fig. 8 (syntype).

Risomurex roseus (Reeve). SARASÚA and ESPINOSA, 1984, Poeyana, no. 273, p. 4, fig. 2A.

Description: Shell average in size for the subgenus, to 15 mm in height; fusiform and solid. Aperture ovate, narrow; columellar lip erect on four-fifths of anterior part, adherent above; one small node on anterior portion and two elongate, stronger nodes at the middle; anal notch fairly large and deep; outer apertural lip slightly crenulate, inner side with five elongate denticles, the second one the strongest. Spire high; protoconch of one and one-half keeled whorls; five rounded, slightly angular postnuclear whorls. Suture impressed. Body whorl with seven low, heavy, rounded axial ribs; apertural varix with five short spines. Spiral sculpture consisting of eight major cords: One on the shoulder, five on the body, the fifth of these shallowest, two smaller on the siphonal canal; other spiral sculpture of, usually, two intermediate threads between each pair of major cords; a small elongate node developed at intersection of spiral cords and axial ribs. Siphonal canal short, narrowly open and slightly bent dorsally. Shoulder cord, third and fifth cord on the body and the two cords on siphonal canal colored dark brown, almost black; protoconch and first spire whorl pink; other parts, including the aperture, light to dark pink.

Lectotype: BMNH 1968458 (here designated).

Dimensions of lectotype: Height 11.1 mm, diameter 6.4 mm.

Type locality: St. Thomas, Virgin Islands (designated by Kemperman and Coomans, 1984, p. 5).

Figured specimens: Fig. 5, BMNH 1968458 (lectotype). Fig. 6, BMNH 1984186 (paralectotype); height 14.8 mm, diameter 8.1 mm; locality unknown. Fig. 7, García Collection; height 10.9 mm, diameter 6.2 mm. Fig. 8, García Collection; height 9.5 mm, diameter 5.0 mm; locality of both 7 and 8: 3 meters, under rubble, Shell Beach, Antigua, B.W.I. Fig. 9, Robinson Collection; height 11.5 mm, diameter 6.4 mm; locality, Punta Rucia, Prov. Puerto Plata, Dom. Rep.

Discussion: Cernohorsky (1978, fig. 23) figured a syntype of *Ricinula rosea* Reeve, noting that the type locality was said by Reeve to be "Island of Masbate [Philippines]." This is an error, but only the first of many that have plagued this unfortunate species. As Cernohorsky stated, although subsequent authors have considered the form to be Caribbean, upon the reference of Tryon (1883, p. 192), the shell illustrated by Warmke and Abbott (1961, pl. 19b) is not conspecific with Reeve's syntypes, nor is the radula figured by Radwin and D'Attilio (1976, text fig. 110) of a muricine species. Cernohorsky is absolutely correct; the problem is that neither of the latter references is based upon the species here referred to *Muricopsis (Risomurex) roseus*. The shell illustrated by Warmke and Abbott is *M. (R.) deformis* (Reeve) and the

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1-3. *Muricopsis (Risomurex) gilbertharrisi* (Weisbord) 78
1. (X2-1/2) PRI 26205 (holotype); height 20.5 mm, diameter 9.9 mm.
Locality: Quebrada Mare Abajo, Cabo Blanco, Venezuela; Mare Fm.
2. (X2-1/2) Rolán Coll.; height 21.3 mm, diameter 10.4 mm.
3. (X20) Houart Coll.; height 9.4 mm, diameter 4.6 mm.
Locality of both: Isla de Margarita, Venezuela.
4, 5. *Muricopsis (Risomurex) withrowi* Vokes and Houart, n. sp. 78
4. (X3) USNM 779868 (holotype); height 16.3 mm, diameter 9.0 mm.
Locality: Curaçao, Neth. Antilles.
5. (a, b X 3; c X 20) IRSNB I. G. 26,738/407 (paratype); height 19.5 mm, diameter 10.0 mm.
Locality: Off Riohacha, Colombia.
6, 7. *Muricopsis (Risomurex) crassicosta* (Benoist) 84
6. (X3) USNM 377394; height 17.3 mm, diameter 9.4 mm.
Locality: Saucats, France; Burdigalian.
7. (X3) USNM 377395; height 16.0 mm, diameter 8.5 mm.
Locality: TU 555, Chipola Fm., Florida; Burdigalian. (Fig. 7b, color pattern as revealed by ultraviolet light).

(All specimens whitened, except figs. 1c, 4, and 7b.)

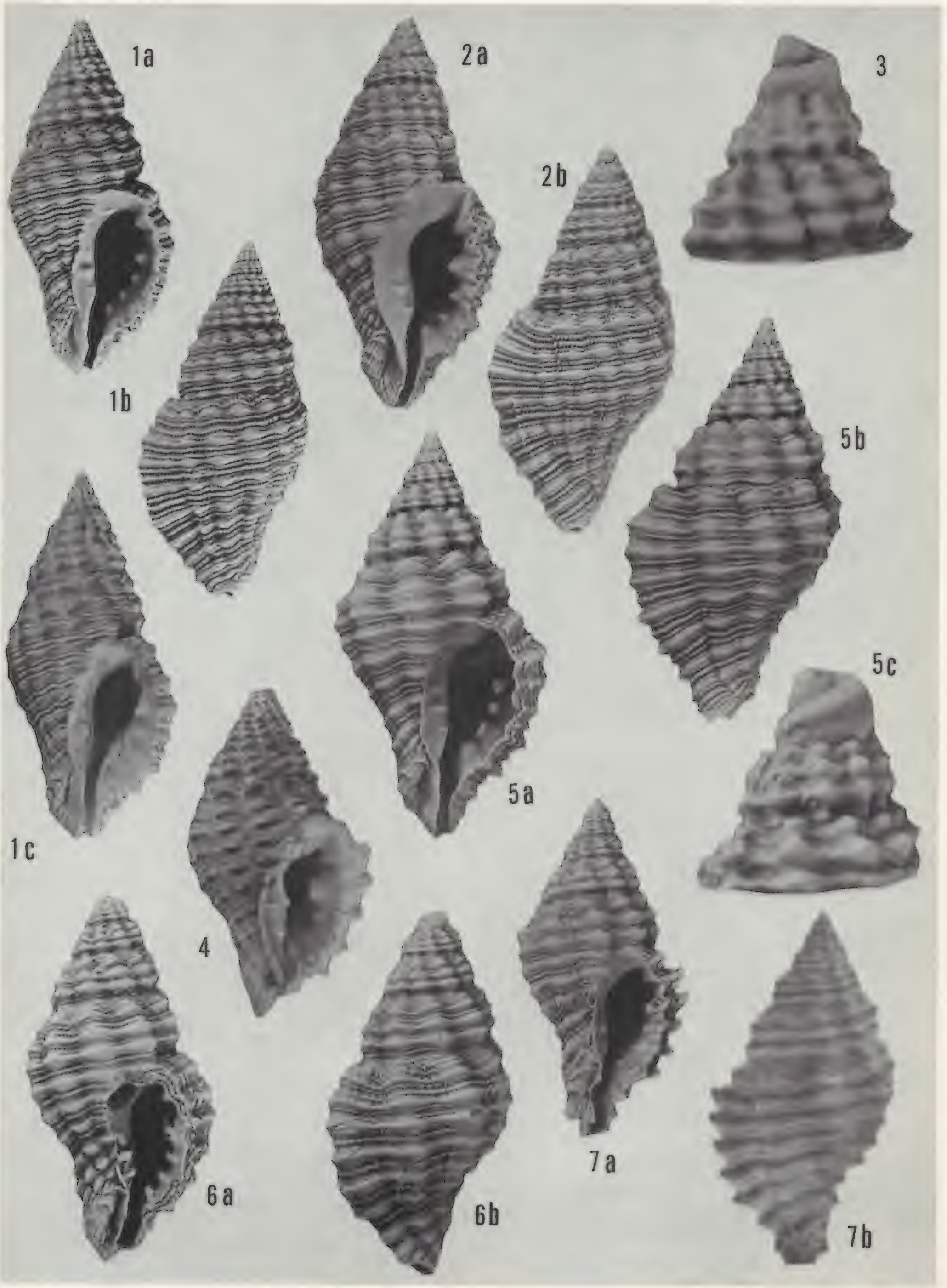

PLATE 3

radula given by Radwin and D'Attilio is an ocenebrine species, presumably *Trachypollia nodulosa* (C. B. Adams, 1845).

As Cernohorsky seemingly confirmed the Indo-Pacific locality of *M. (R.) roseus*, Vokes and Vokes (1983, p. 24) concluded that the correct name for the Carribbean species must be "*Ricinula*" *rutila* Reeve (see below), which has a similar color pattern but not exactly the same, as subsequent investigation proved. A visit to the British Museum (Natural History) turned up a number of examples of "*Ricinula*" *rosea*, all of which match the syntypes, and none of which has an Indo-Pacific locality. It seems obvious that, as was frequently the case in the Cuming Collection, the locality is in error and "*R.*" *rosea* is the Caribbean species Tryon first recognized.

In the type collection of the British Museum (Natural History) there are four specimens segregated as "syntypes." One of these (here figured, pl. 1, fig. 5) seems to match the Reeve illustration best and, at some point, an unknown person has marked an "x" in the aperture with pencil. This specimen is here designated as lectotype. In the collections there is a fifth specimen, also from the Cuming Collection but with no locality data, that is better than any of the syntypes. It is also figured (pl. 1, fig. 6) as a paralectotype.

This species is less common than *M. caribbaeus* and *M. deformis*, both of which occur in very shallow water. The records for *M. roseus* range to 30 m off the coast of Jamaica (Humfrey, 1975, p. 139), and as much as 25 m on the south coasts of the Dominican Republic (La Caleta - David G. Robinson, personal communication). But it also has been taken in very shallow water in Antigua, B.W.I. (3 m, García Collection and Houart Collection), on the north coast of the Dominican Republic (pl. 1, fig. 9, collected in 1 m by David G. Robinson) and in beach drift from Turks and Caicos (David G. Robinson). Sarasúa and Espinosa (1984, p. 4) state that 15 examples were taken alive at Playa Santa Lucia, Nuevitas, Camaguey, Cuba, in depths from 1.5 to 20 m on both rocks and coral reefs. Kemperman and Coomans (1984, p. 5) report it from St. Thomas, Virgin Islands (which they designate as type locality) and Pointier *et al.* (1982, p. 9) list it from Guadeloupe, French Antilles.

The species has not been reported from the northern coast of South America but Gibson-Smith (*in litt.*, 5 Jan. 1985) and D.L.N. Vink (*in litt.*, 3 Jan. 1985) both report taking the species along the coast of Sucre State, Venezuela. These Venezuela shells differ slightly from the typical *M. roseus* in that the color pattern is reversed between the dark and light cords on the upper part of the whorl. In typical *M. roseus* there are two light-colored cords on the shoulder and a single dark one at the periphery. In the South American shell there is one light-colored cord at the shoul-

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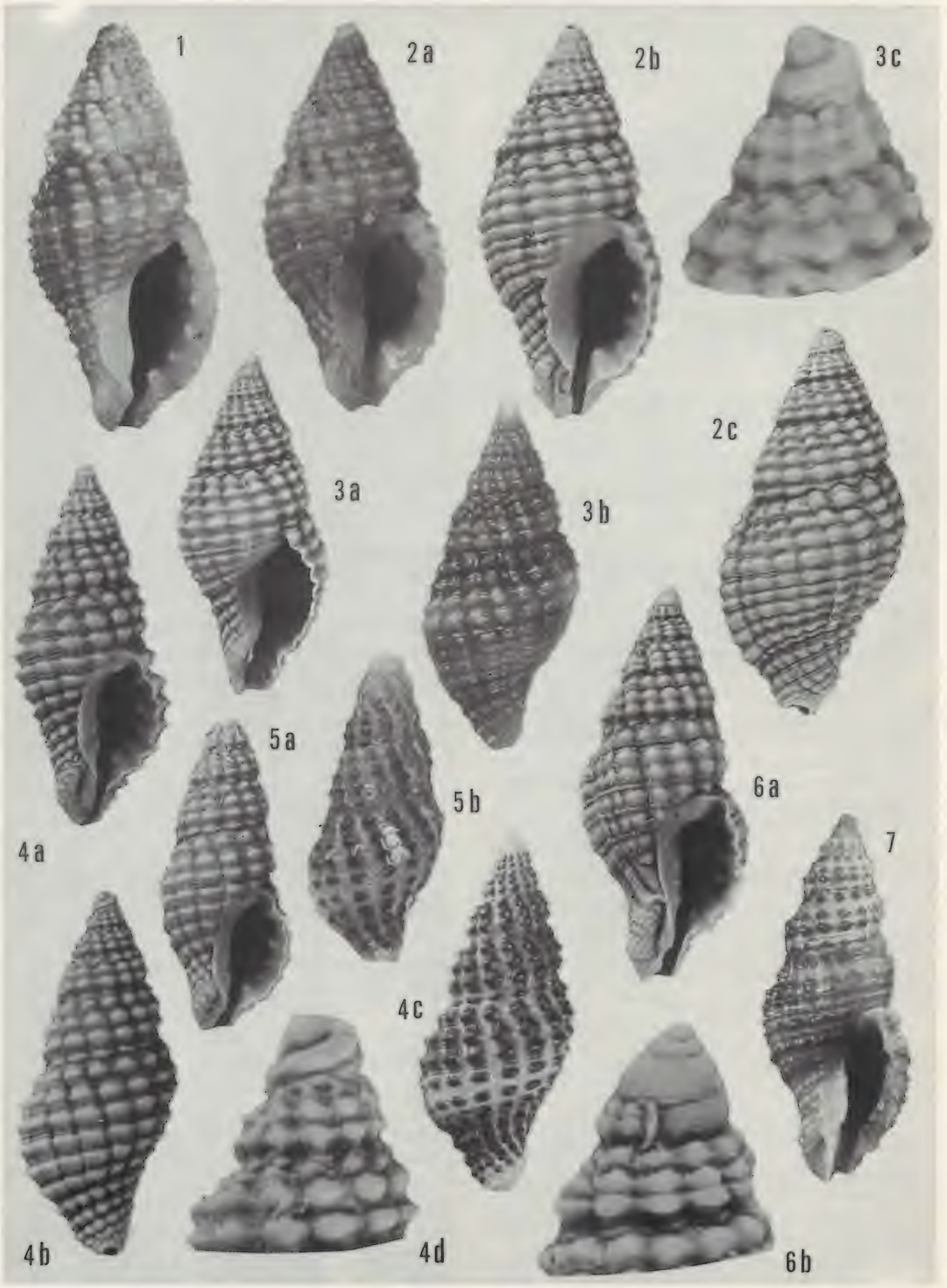
1-3. *Muricopsis (Risomurex) fusiformis* (Gmelin) 81
1. (X4) Berlin Mus. 37204 (lectotype-*Cantharus multigranosus* Maltzan; height 14.4 mm, diameter 6.7 mm.
2. (X4) MNHN (lectotype); height 13.6 mm, diameter 6.4 mm.
3. (a,b X4; c X20) MNHN (paralectotype); height 11.9 mm, diameter 5.1 mm.
Locality of all: Ile de Gorée, Senegal.
4, 5. *Muricopsis (Risomurex) suga* (Fischer-Piette) 82
4. (a-c X5; d X20) USNM 859067; height 9.9 mm, diameter 4.0 mm.
5. (X4) MNHN (paralectotype); height 10.8 mm; diameter 4.5 mm.
Locality of both: Ile de Gorée, Senegal.
6-7. *Trachypollia turricula* (Maltzan) 81
6. (a X5; b X20) USNM 859068; height 11.0 mm, diameter 4.6 mm.
Locality: Corimba, Luanda, Angola.
7. (X4) Berlin Mus. 37205 (lectotype); height 12.5 mm, diameter 5.4 mm.
Locality: Ile de Gorée, Senegal.

(All specimens whitened except 2a, 3b, 4c, 5b, and 7)



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der and two dark ones at the periphery. Otherwise, there is no morphological difference between these shells and the Antillian ones, and it is considered they are only a local color variant.

No examples are known from the coast of Central America or North America, with the exception of Maxwell Smith (1953, pl. 20, fig. 1), who correctly illustrated the species but stated that his specimen was from "Long Key, Florida." The only Long Key known to the writers is at the mouth of Tampa Bay, and this is a very suspect locality. It is assumed the species is found only in the Antilles, and the northern coast of South America.

MURICOPSIS (RISOMUREX) SCHRAMMI (Crosse)
Plate 1, fig. 1

Engina schrammi CROSSE, 1863, Jour. de Conchyl., v. 11, p. 82, pl. 1, fig. 7.

Engina rosea (Reeve). TRYON, 1883, Man. Conch., v. 5, p. 192, in part, pl. 62, fig. 35 only.

Not *Risomurex schrammi* (Crosse). OLSSON and MCGINTY, 1958, Bulls. Amer. Paleontology, v. 39, no. 177, p. 41, pl. 2, figs. 2, 2a (=*R. deformis* Reeve).

Not *Ocenebra (Risomurex) schrammi* (Crosse). ABBOTT, 1974, American Seashells, p. 184 (= *R. deformis* Reeve).

Not *Muricopsis schrammi* (Crosse). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 171, pl. 2, fig. 1, text fig. 111 (protoconch–worn), 112 (radula)(=*R. deformis* Reeve).

Not *Risomurex schrammi* (Crosse). KAICHER, 1979, Card Cat. World Wide Shells, pack no. 20 (Muricidae IV), no. 2010 (=*R. deformis* Reeve).

Risomurex schrammi (Crosse). KEMPERMAN and COOMANS, 1984, Zool. Mus. Univ. Amsterdam, Bull., v. 10, no. 1, p. 3, figs. 6 (holotype), 7 (J. de C., v. 11, pl. 1, fig. 7).

Not *Risomurex schrammi* (Crosse). SARASÚA and ESPINOSA, 1984, Poeyana, no. 273, p. 3, fig. 5A (=*R. deformis* Reeve).

Description: "Coquille imperforée, épaisse, subglobuleuse, atténuée aux deux extrémités et de couleur rose. Les tours de spire, au nombre de cinq, sont légèrement convexes, munis de côtes longitudinales obtuses, et ornés transversalement de nombreuses et élégantes lignes de nodulations: une seule de ces lignes, placée près de la suture, est d'un brun noirâtre très-intense: sur le dernier tour les lignes transverses, d'un brun noirâstre, sont au nombre de trois, l'une près de la suture, la seconde vers la partie médiane du tour, la troisième plus près de la base. La columelle est ridée et comme plissée, le bord droit épais et armé de quatre dents, dont l'une (la plus rapprochée du point d'insertion) est plus grosse que les autres. L'ouverture est, à peu près, droite, resserrée par les dents marginales, et par suite étroite: son intérieur est d'un rose violacé. La base de la coquille est canaliculée et sensiblement prolongée. - Longueur 9, plus grand diamètre 6 millimètres." (Crosse, 1863)

Holotype: Coll. Jour. de Conchyl., Mus. Natl. Hist. Nat. Paris.

Dimensions of holotype:Height 8.8 mm., diameter 5.5 mm.

Type locality: Guadeloupe, French Antilles.

Figured specimen: Holotype.

Discussion: In a recent paper Kemperman and Coomans (1984) have demonstrated that the Caribbean shell usually considered to be *Risomurex schrammi* (Crosse) is not that species but a different one, which they describe as *R. mosquitensis*. Although we are in complete agreement with their assessment of the two being different, we cannot accept the new species as being distinct from *Risomurex deformis* (Reeve) and it is so treated herein.

"Engina" schrammi was described from Guadeloupe, but to the writers' knowledge no subsequent specimens have ever been taken. In the extensive collections of mollusks from that island listed by Pointier *et al.* (1982) and housed in the Museum National d'Histoire Naturelle, Paris, there are no examples of *Risomurex* except *M. roseus* and *M. caribbaeus* (as *muricoides*).

The holotype is very faded and today is pale peach color with three narrow brown spiral cords. Except for the width of the dark bands the shell is indistinguishable from *M. roseus*. Since evidently no one has ever seen another example, we suspect that the type specimen is only an aberrent example of *M. roseus* and Tryon probably was correct when he placed *Engina schrammi* in the synonymy of *"E." rosea* (Reeve) (1883, p. 192).

As is discussed under *M. (R.) deformis* above, the name *"schrammi"* was used by Olsson and McGinty (1958, p. 41, pl. 2, figs. 2, 2a) for the form that occurs along the coast of Panamá and Costa Rica, which they cited as the type species of their new genus *Risomurex*. When one examines the original illustration of *E. schrammi* (refigured in Kemperman and Coomans, 1984, fig. 7) this is an understandable error. The most significant difference between

M. deformis and *"E." schrammi* is that in the first the dark color lines are *between* the spiral cords* and in the second it is the spiral cords themselves that are dark. However, the illustration gives the distinct impression of a dark shell with light spiral cords, of which only three are black. As can be seen from the photograph of the holotype (pl. 1, fig. 1; also figured in Kemperman and Coomans, 1984, fig. 6) this is not the case. The entire shell is pink, except for the three dark spiral cords, as noted in the description by Crosse.

MURICOPSIS (RISOMUREX) CARIBBAEUS
(Bartsch and Rehder)
Plate 2, figs. 7-9

Fusus muricoides C. B. Adams, 1845, Boston Soc. Nat. Hist., Proc., v. 2, p. 3; CLENCH and TURNER, 1950, Occ. Pap. Moll., Harvard Univ., v. 1, no. 15, p. 313, pl. 39, fig. 9 (holotype). (*Non Fusus muricoides* Deshayes, 1835).

Tritonalia (Ocinebrina) caribbaea BARTSCH and REHDER, 1939, Smithsonian Misc. Coll., v. 98, no. 10, p. 7, pl. 1, fig. 1.

Ocenebra (Ocinebrina) muricoides (Adams). ABBOTT, 1954, Nautilus, v. 68, p. 44, pl. 2, fig. 2 (holotype of *caribbaea*).

Risomurex muricoides (Adams). OLSSON and MCGINTY, 1958, Bulls. Amer. Paleontology, v. 39, no. 177, p. 41, pl. 2, figs. 1, 1a.

Ocenebra (Risomurex) muricoides (Adams). ABBOTT, 1974, American Seashells, p. 184, fig. 1922.

Risomurex muricoides (Adams). HUMFREY, 1975, Sea Shells of the West Indies, p. 140, pl. 16, fig. 9.

Risomurex muricoides (Adams). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 168, pl. 2, fig. 2.

Morula rutila (Reeve). CERNOHORSKY, 1978, Rec. Auckland Inst. Mus., v. 15, p. 78, in part, not fig. 27 (*not* of Reeve).

Muricopsis muricoides (Adams). POINTIER, ERAVILLE, and DELPLANQUE, 1982, Xenophora, no. 9, p. 9.

Risomurex caribbaeus (Bartsch and Rehder). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (MARI Publ. 54), p. 24, pl. 12, fig. 4 (holotype of *F. muricoides* Adams).

Risomurex muricoides (Adams). KEMPERMAN and COOMANS, 1984, Zool. Mus. Univ. Amsterdam, Bull., v. 10, no. 1, p. 3, fig. 9.

Risomurex muricoides (Adams). SARASÚA and ESPINOSA, 1984, Poeyana, no. 273, p. 4, fig. 2B.

Description: Shell of average size for the subgenus, height to 15 mm; fusiform and solid. Aperture narrow and ovate; columellar lip adherent its entire length, two small nodes on the anterior part; anal notch moderately deep; outer apertural lip weakly crenulate on inner side with five small, elongate denticles, the second of which is strongest, the fifth barely visible. Spire high and acute; protoconch of one and one-fourth slightly carinate whorls; five or six elongate and convex postnuclear whorls. Suture impressed. Body whorl with seven or eight large and moderately strong axial ribs. Spiral sculpture consisting of eight major cords: one on the shoulder, five on the body, and two on the siphonal canal; one or two weak intermediate spiral threads between each pair of major cords. Small elongate nodes appearing at intersection of axial ribs and spiral cords, giving the shell a nodulose appearance. Siphonal canal short, narrowly open, slightly recurved dorsally. Shell color from light to dark brown, with certain of the spiral cords white: the anteriormost on the spire whorls, the third and fifth on the body, and the two smaller on the siphonal canal; protoconch white or slightly stained with brown.

Holotype: USNM 472617.

Dimensions of holotype: Height 8.3 mm, diameter 4.0 mm.

Type locality: "Old Providence Island, Caribbean Sea" (= Isla de Providencia, Colombia).

Figured specimens: Fig. 7, MCZ 186098 (holotype - *Fusus muricoides* C. B. Adams); height 15.3 mm, diameter 7.1 mm; locality, Jamaica. Fig. 8, USNM 820639; height 13.9 mm, diameter 7.0 mm; locality TU R-389. Fig. 9, USNM 472617 (holotype).

Discussion: The name *"Tritonalia" caribbaea* Bartsch and Rehder has been universally accepted as a junior synonym of *"Fusus" muricoides* since Abbott's 1954 paper. Unfortunately, overlooked by all was the fact that *Fusus muricoides* Adams is preoccupied by *Fusus muricoides* Deshayes, 1835, a French Eocene fossil. Only recently did Cernohorsky (1978, p. 78) call this to our attention, suggesting that the name *"Ricinula" rutila* Reeve was the correct designation for the species. As is discussed below, this is incorrect and, therefore, the proper name is *M. (R.) caribbaeus*.

Of all the species of *Risomurex*, this is the most common and widespread. We have it from the Florida Keys, Yucatan, and the Bay Islands, to Costa Rica and

*The light-colored spiral cords, which are nodulated by the axial ridges, give the appearance of a shell covered by grains of rice. Presumably this is the origin of the name *Risomurex*, as *riso* is the Italian (but not the Latin!) word for rice.

Panamá. Adams (1845, p. 3) and Humfrey (1975, pl. 16, fig. 9) recorded it from Jamaica and we have taken it at several localities in the Dominican Republic. Sarasúa and Espinosa (1984, p. 4) note that the form is very abundant on Cuban coral reefs. Pointier *et al.* (1982, p. 9) list it from Guadeloupe and Radwin and D'Attilio (1976, pl. 2, fig. 3) illustrate an example from Barbados. The species is found in the same environment as *M. (R.) deformis*, occurring in even shallower water, under rocks and coral slabs that are exposed at low tide.

Gibson-Smith (*in litt.*, 5 Jan. 1985) has collected a number of juvenile specimens on Isla La Tortuga, off the coast of Venezuela, but otherwise there are no records from northern South America. Presumably, it is replaced by *M. withrowi* and *M. gilbertharrisi*, which occupy basically the same environmental niche.

MURICOPSIS (RISOMUREX) GILBERTHARRISI
(Weisbord)
Plate 3, figs. 1-3

Drupa (Morula) gilbertharrisi WEISBORD, 1962, Bulls. Amer. Paleontology, v. 42, no. 193, p. 295, pl. 26, figs. 12-14.

?*Risomurex gilbertharrisi* (Weisbord). GIBSON-SMITH and GIBSON-SMITH, 1972, VI Conf. Geol. Caribe, Mem., p. 474.

Description: Shell large for the subgenus, to 22 mm in height; elongate and solid. Aperture ovate, large; columellar lip with one or two small denticles on anterior part; adherent above and erect on four-fifths of anterior part; anal notch strong and deep; outer apertural lip slightly crenulated, with five low denticles on the inner side, the second slightly larger. Spire high; protoconch of one and one-half keeled whorls; six rounded and elongate postnuclear whorls. Suture indistinct. Body whorl with ten to twelve low, rounded axial ridges; no other axial sculpture. Spiral sculpture consisting of eight major cords; one on the shoulder, five on the body and two on the siphonal canal, accompanied by three squamose threads between each pair of major cords. Siphonal canal short, narrowly open, slightly recurved at tip. Color pink with darker spots where the spiral cords cross the varices; aperture white, margined with pink or yellow.

Holotype: PRI 26205.

Dimensions of holotype: Height 20.5 mm, diameter 9.9 mm.

Type locality: Lower Mare Formation, in stream 100 meters west of Quebrada Mare Abajo, Cabo Blanco, Venuzuela.

Figured specimens: Fig. 1, PRI 26205 (holotype). Fig. 2, Rolán Collection; height 21.3 mm, diameter 10.4 mm. Fig. 3, Houart Collection; height 9.4 mm, diameter 4.6 mm. Locality of specimens in figs. 2 and 3: Isla de Margarita, Venezuela; Recent.

Discussion: Originally described from the Early Pliocene lower Mare Formation of Venezuela, this form has been discovered living in 0.5 - 1 meter, on algae-covered rocks along the coast of Isla de Margarita, by Emilio Rolán, of Vigo (Pontevedra), Spain, who sent the figured material to Houart for identification. In the Gibson-Smith collection (*in litt.*, 5 Jan. 1985) there are a number of beach specimens from Juan Griego, Isla de Margarita, as well as a few from Playa Colorado, Santa Fe, Estado Sucre, but this seems to be the distributional extent of the species. Elsewhere it is replaced by *M. withrowi*.

The Mare Formation, based on the planktic foraminifera, is now considered to be Late Pliocene in age and many of the species described by Weisbord from the formation have subsequently been discovered in the Recent fauna (see Gibson-Smith and Gibson-Smith, 1979, pp. 24-30).

The environment of deposition of the lower Mare Formation must have been very near to that in which the modern specimens of *M. gilbertharrisi* were collected. The fauna comprises numerous examples of *Diodora, Fissurella, Tegula, Calliostoma,* and *Turbo*, plus the shallow-water muricid species that one would expect on a shallow, rocky, Caribbean coast.

MURICOPSIS (RISOMUREX) WITHROWI
Vokes and Houart, n. sp.
Plate 3, figs. 4, 5

Risomurex roseus (Reeve). GIBSON-SMITH and GIBSON-SMITH, 1972, VI Conf. Geol. Caribe, Mem., p. 474 (*not* of Reeve).

Description: Shell large for the subgenus, to 20 mm in height; solid and fusiform. Aperture ovate; columellar lip with two or three small denticles, reflecting the nodulose sculpture of the shell; adherent above and erect on about three-fourths of its anterior part; outer apertural lip crenulated, with five strong denticles on its inner side, the strongest being the second posterior one; anal notch deep and narrow. Spire

high and acute; protoconch of one and one-half keeled whorls; six convex, slightly angulate postnuclear whorls. Suture impressed and slightly undulating. Body whorl with seven to nine low, broad axial ridges; no other axial sculpture except growth lamellae. Spiral sculpture consisting of eight major cords, more apparent and darker colored on the axial ribs, giving a nodulose appearance to the shell, and distributed as follows: one on the shoulder; five on the body; and two on the siphonal canal; two or three somewhat squamose threads intercalated between each pair of major spiral cords. Siphonal canal short, open, very slightly recurved dorsally at the tip. Color mauve or orange to light brown, or almost black, with darker-colored spots where the spiral cords cross the ribs; aperture white, edged by pink.

Holotype: USNM 779868.

Dimensions of holotype: Height 16.3 mm, diameter 9.0 mm.

Paratype: IRSNB I. G. 26,738/407; height 19.5 mm, diameter 10.0 mm; locality, off Riohacha, Colombia, exact data unknown.

Type locality: Curaçao, Netherlands Antilles.

Figured specimens: Fig. 4, USNM 779868 (holotype). Fig. 5, IRSNB I. G. 26,738/407 (paratype).

Discussion: This new species is named for the late Carl Withrow, of St. Petersburg, Florida, who originally recognized the paratype specimen as new and sent it to the senior author for description. It may be compared with three more or less closely related species. From *M. (R.) deformis* it differs by its greater size, its color, and by its more elaborate spiral sculpture. The latter species has strong nodules at the intersection of the spiral cords and axial ridges, which are light pink on a dark-colored shell; *M. (R.) withrowi* has darker nodules on a light brown or orange shell. The spiral cords of *M. deformis* are larger and closer together. The columellar lip of *M. deformis* is very weakly erect or somewhat adherent on its anterior part, but that of *M. withrowi* is detached and erect on three-quarters of its anterior part. *Muricopsis roseus* is a much smaller shell with a different aperture, different spiral sculpture and a different, slightly appressed suture.

The most closely related species, *M. (R.) gilbertharrisi*, also occurs in northern South America, but so far as is known, the two do not occur together. It is possible that the two are only ecologic varients but, on the basis of our material, *M. gilbertharrisi* may be distinguished from *M. withrowi* by having a more narrow, elongated form, with lower and more numerous axial ribs; there being seven to nine ribs in *M. withrowi* and ten to twelve ribs in *M. gilbertharrisi*. The spiral cords are stronger in *M. withrowi* than in *M. gilbertharrisi*, and the labral denticles are larger.

Nevertheless, the distribution pattern of the two species is unusual, with *M. gilbertharrisi* being confined to the Isla de Margarita region and *M. withrowi* occurring all along the coast from Colombia and Venezuela, as far east as the islands of Trinidad and Tobago, as well as the offshore islands of the Netherlands Antilles. Originally described from the Caracas area, *M. gilbertharrisi* evidently is now found only farther to the east–and surrounded on three sides by the presumably younger form. Logic dictates that the two forms should be considered one species but the morphology of the two is sufficiently distinct that the authors believe the separation is valid.

Both of these South American species more closely resemble the Early Miocene *M. crassicosta* (Benoist) than they do the other living members of *Risomurex*. The three share the extremely ornate spiral sculpture, which consists of three squamose intermediate threads (one larger flanked by two smaller) between each pair of major spiral cords. Only *M. roseus* approaches this type of sculpture and in that form the major spirals greatly exceed in strength the intercalary threads.

The color pattern of the two South American species is more akin to that of *M. necocheanus* than to any of the other American forms of living *Risomurex*, in that the shell is lighter-colored with the nodules darker-colored. This is also the pattern in the ancestral *M. crassicosta* and in the living West African *M. suga*. In *M. deformis* the shell is dark and the nodules are lighter; in *M. roseus, M. rutilus, M. caribbaeus*, and *M. fusiformis* light-colored ribs alternate with dark ones.

According to Dr. Rudo von Cosel, of Giessen, Germany (*in litt.*, 1 June, 1984) the species is found "occurring sympatrically with *T. nodulosa*. It lives on rocky shores (mineral, not coral), under stones from 0-1 m," in the vicinity of Sta. Marta, Colombia. Several specimens, including

the holotype, have also been taken on the island of Curaçao, Netherlands Antilles, as well as on Aruba (D. L. N. Vink, *in litt*, 8 Nov. 1977). Gibson-Smith advises (*in litt.*, 5 Jan. 1985) that this is the species cited as "*Risomurex roseus*" (Gibson-Smith and Gibson-Smith, 1972, p. 474) from Borburata (approximately 120 km west of Caracas), where they have taken numerous specimens. The Gibson-Smith collection also contains examples from as far east as Carenero (approximately 80 km east of Caracas), Venezuela, and Islas Los Roques. Several embryonic specimens from Isla La Tortuga (about halfway between Los Roques and Margarita) cannot be assigned to either *M. gilbertharrisi* or *M. withrowi* with any degree of confidence. All of the Gibson-Smith material was taken in association with coral reefs or with cemented beach-rock (Playa Grande only), in very shallow water. In the collections of the American Museum of Natural History there are several lots of specimens (141494, 93352, 191664) from Tobago and one (93352) from Trinidad. All of these specimens are unmistakably identifiable as *M. withrowi*, with about nine axial ribs. They are all beach specimens with no ecologic data, unfortunately.

MURICOPSIS (RISOMUREX) RUTILUS (Reeve)
Plate 1, figs. 2-4

Ricinula rutila REEVE, 1846 [plate dated "1856" in error], Conch. Icon., v. 3, *Ricinula*, pl. 6, fig. 49.

Engina rutila (Reeve). TRYON, 1883, Man. Conch., v. 5, p. 192, pl. 62, fig. 36.

Muricopsis angolensis (Odhner). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 165, pl. 27, fig. 11 (*not* of Odhner).

Morula rutila (Reeve). CERNOHORSKY, 1978, Rec. Auckland Inst. Mus., v. 15, p. 78, fig. 27 (syntype BMNH 1968461).

Not *Risomurex rutilus* (Reeve). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (MARI Publ. 54), p. 24 (= *M. roseus* Reeve).

Description: Shell of average size for subgenus, to 13 mm in height; fusiform and elongate. Aperture ovate and narrow; columellar lip adherent above, detached below, with one small denticle and one small fold on the anterior end, the fold extending into the aperture; anal notch deep and large, in a reversed "U" form; outer apertural lip smooth, with five denticles on the inner side, the second one strongest, the remainder smaller. Spire high; protoconch of one and one-fourth keeled whorls; six slightly convex postnuclear whorls. Suture weakly impressed. Body whorl with seven rounded axial ridges; no other axial sculpture, except growth lines; apertural varix with five short spines. Spiral sculpture consisting of eight cords: one small one on the shoulder, five strong on the body and two small on the siphonal canal; other spiral sculpture consisting of two or three intermediate threads between each pair of major cords. At the intersection of axial ribs and spiral cords small elongate nodes developed, giving a nodulose appearance to the shell. Siphonal canal short, open and slightly recurved dorsally. Shell color gray, siphonal canal darker; shoulder of each whorl darker, with one small brown spot appearing below each node; first, second, fourth, and fifth spiral cord on the body white, the third dark gray; the aperture white with darker bands.

Lectotype: BMNH 1968461 (here designated).

Dimensions of lectotype: Height 12.0 mm, diameter 5.5 mm.

Type locality: Busua Island, Ghana, West Africa (here designated).

Figured specimens: Fig. 2, BMNH 1968461 (lectotype). Fig. 3, Houart Collection; height 13.0 mm, diameter 6.2 mm; locality, Busua Island, Ghana. Fig. 4, Vokes Collection; height 7.8 mm, diameter 4.0 mm; locality, Takoradi, Ghana.

Discussion: Cernohorsky (1978, fig. 27) figured a syntype of "*Ricinula*" *rutila* Reeve and suggested that this was the name to be used for the pre-occupied "*Fusus*" *muricoides* Adams, of the Caribbean. Vokes and Vokes (1983, p. 24) disagreed with this assessment suggesting, instead, that the name should be used for the Caribbean species that was being called "*Risomurex roseus*," as the latter was assumed to be an Indo-Pacific form. As noted above, subsequent investigation proved *M. roseus* is, in fact, the species that has been so considered and is from the Caribbean, not the Indo-Pacific, in spite of the "type locality" of "Island of Masbate."

Thus, the problem became, what is "*Ricinula*" *rutila*? It is colored very like the Caribbean *M. roseus*, but it seems to have a more narrow outline. Searching the British Museum and the Paris Musuem did not uncover any locality information. Then, in the collection of Houart we discovered, under the label "*Muricopsis angolensis*," a specimen (figured here, pl. 1, fig. 3) that is undoubtedly Reeve's species. The misidentification is a result of Radwin and D'Attilio's (1976, p. 165) treatment of

the species in question as "*Muricopsis angolensis* (Ohdner, 1922)." Their description and illustration are clearly of this form and not Odhner's species, which is a synonym of *Orania fusulus* (Brocchi, 1814).

Therefore, we can now say that *M. roseus* is the Caribbean form; *M. rutilus* is the West African form; and, although closely related, they are not the same. In veiw of geography, it is not surprising that this African species is similar in general form to the members of the group in the northern South American region, such as *M. withrowi* and *M. gilbertharrisi*, but it has the banded color pattern of the Caribbean *M. roseus* and *M. caribbaeus*.

The habitat of *M. rutilus* is similar to other members of the subgenus. Peter Ryall, of Takoradi, Ghana, who supplied the specimen with protoconch figured (pl. 1, fig. 4) advises (*in litt.*, 27 Oct. 1984) that "this shell is quite uncommon here, inhabiting rocky areas at a depth of 10 to 15 meters." The areal range of the form is not known at this time.

MURICOPSIS (RISOMUREX) FUSIFORMIS (Gmelin)
Plate 4, figs. 1-3

"Le Loset" ADANSON, 1757, Hist. Nat. Senegal, Coquillages, p. 132, pl. 9, fig. 23.

Murex fusiformis GMELIN, 1791, Syst. Nat., ed. 13, p. 3549 (ref. to "Le Loset" Adanson).

Ocinebrina loset Adanson. JOUSSEAUME, 1882, Rev. Mag. Zool., (Ser. 3) v. 7, p. 332.

Cantharus (Pollia) multigranosus VON MALTZAN, 1884, Dtsch. Malak Gesell., Nachr., v. 16, no. 5, p. 68.

Tritonalia (Ocinebrina) fusiformis (Gmelin). FISCHER-PIETTE, 1942, Jour. de Conchyl., v. 85, p. 227, pl. 7, figs. 5-8 (syntypes); FISCHER-PIETTE and NICKLÈS, 1946, Jour. de Conchyl., v. 87, p. 60.

Tritonalia fusiformis (Gmelin). KNUDSEN, 1956, Atlantide-Rept., no. 4, p. 26 (in part), *not* pl. 2, fig. 20 (= *Trachypollia nodulosa*).

[?Ocinebrina] fusiformis (Gmelin). VOKES, 1971, Bulls. Amer. Paleontology, v. 61, no. 268, p. 52.

?Ocinebrina fusiformis (Gmelin). FAIR, 1976, *Murex* Book, p. 45.

Description: Shell average in size for the subgenus, to 15 mm in height; fusiform and solid. Aperture ovate, narrow; columellar lip erect on four-fifths of anterior part, adherent above; one weak denticle occasionally developed at anterior end; anal notch broad and ill-defined; outer apertural lip slightly crenulated, with five low denticles on the inner side, all of approximately the same size. Spire high; protoconch of one and one-half keeled whorls; six postnuclear whorls. Suture indistinct. Body whorl with 13 to 15 low flattened ridges; no other axial sculpture. Spiral sculpture of, on the spire whorls four, on the body whorl approximately 12 major cords: nine on the body portion and three on the canal; with three very fine threads between each pair of major cords. Siphonal canal short, narrowly open, slightly recurved at tip. Color reddish-brown, with a white band paralleling the two spiral cords that number third and fourth anterior to the suture, appearing adjacent to the suture on spire whorls; tops of the first two sprial cords anterior to suture tipped by golden blotches; aperture same color as shell.

Lectotype: MNHN (here designated), specimen figured by Fischer-Piette, 1942, pl. 7, fig. 6.

Dimensions of lectotype: Height 13.6 mm, diameter 6.4 mm.

Type locality: Ile de Gorée, Senegal, West Africa.

Figured specimens: Fig. 1, Berlin Mus. 37204 (lectotype-*Cantharus multigranosus* Maltzan, here designated); height 14.4 mm, diameter 6.7 mm. Fig. 2, MNHN (lectotype). Fig. 3, MNHN (paralectotype, here designated); height 11.9 mm, diameter 5.1 mm. Locality of all: Ile de Gorée, Senegal.

Discussion: This species has been known since the time of Adanson but does not seem to have been identified by any modern collectors. Fischer-Piette (1942, p. 227) noted that it had not been recognized since Adanson and the intervening years do not seem to have changed the situation. It was particularly misunderstood by Knudsen (1956, p. 26) who combined, under the name *Tritonalia fusiformis*, not only *"Tritonalia" suga*, which is another species of *Risomurex* (see below), but also *"Cantharus (Pollia)" turricula* Maltzan, 1884, which is a *Trachypollia*, and *"Cantharus (Pollia)" subsinuatus* Maltzan, 1884, which is a synonym of *C. turricula* Maltzan. The specimen illustrated, moreover, is none of these but is *Trachypollia nodulosa* (C. B. Adams, 1845). Only one of the names included by Knudsen is a true synonym, that named *"Cantharus (Pollia)" multigranosus* Maltzan 1884; a syntype is figured here (pl. 4, fig. 1) and designated as lectotype.

The above-mentioned species share a type locality and a small, nodulose, non-varicate shell-shape but little more. In the two here referred to *Risomurex* the protoconch is of one and one-half keeled

whorls. The species of *Trachypollia* have a multi-whorled, conical protoconch. A syntype of "*C.*" *turricula* is figured (pl. 4, fig. 7) and designated as lectotype; another example is figured (pl. 4, fig. 6) showing the nature of the protoconch.

The color of each of these species is different, also. *Muricopsis fusiformis* is most like the Caribbean examples of *Risomurex*, having a shell of an overall reddish-brown color with a light-colored band at the periphery. The tops of the nodes on the two spiral cords immediately anterior to the suture are topped with a golden color, similar to *M. rutilus*. *Muricopsis suga*, on the other hand, is light-colored with dark reddish-brown tubercules, which are smaller and less darkly colored in a zone that gives a superficial resemblance to the light band of *M. fusiformis* but which is more anteriorly located, so that the spire of *M. suga* does not show a light band but that of *M. fusiformis* has a light band just posterior to the suture.

Inasmuch as Gmelin based his species "*Murex*" *fusiformis* on "Le Loset" of Adanson, the type lot of Le Loset is the type lot of *M. fusiformis*. In the Adanson collection, studied by Fischer-Piette (1942, p. 227, pl. 7, fig. 5) there are five examples, three large and two small. Fischer-Piette did not designate a lectotype but figured one of the specimens as "un exemplaire X 2." He indicated that it is the one at the upper right in his figure 5; this specimen is here designated as lectotype and refigured (pl. 4, fig. 2). One of the two smaller examples, that one at the lower left side of Fischer-Piette's illustration, is designated as a paralectotype and figured here (pl. 4, fig. 3). It has a well-preserved *Risomurex*-type keeled protoconch; however, the specimen on the right side is an example of *Trachypollia turricula*, also with a good protoconch but of the multi-whorled type, which is doubtless part of the reason for confusion between the two forms.

So far as is known, the species is found only at Ile de Gorée, Senegal. Knudsen (*ibid.*) cited the species as occurring from the Cape Verde Islands to Angola, but as noted above, due to confusion of several different species, this distribution is suspect. Certainly, the example that he figures from the Cape Verde locality is *Trachypollia nodulosa* and in collections of the Museum National d'Histoire Naturelle, Paris, all material collected from Luanda, Angola, is referable to *Trachypollia turricula*.

MURICOPSIS (RISOMUREX) SUGA
(Fischer-Piette)
Plate 4, figs. 4, 5

"Le Suga" Adanson, 1757, Hist. Nat. Senegal, Coquillages, p. 132, pl. 9, fig. 24.

Tritonalia (Ocinebrina) suga FISCHER-PIETTE, 1942, Jour. de Conchyl., v. 85, p. 229, pl. 7, figs. 9, 10.

Tritonalia (Ocinebrina) fusiformis var. *suga* (Fischer-Piette). FISCHER-PIETTE and NICKLÈS, 1946, Jour. de Conchyl., v. 87, p. 61.

Tritonalia fusiformis (Gmelin). KNUDSEN, 1956, Atlantide-Rept., no. 4, p. 26 (in part).

[?Ocinebrina] suga (Fischer-Piette). VOKES, 1971, Bulls. Amer. Paleontology, v. 61, no. 268, p. 126.

Ocinebrina suga (Fischer-Piette). FAIR, 1976, *Murex* Book, p. 79, pl. 22, fig. 332 (not fig. 331, as stated) (lectotype-MNHN Paris).

Description: Shell small for the subgenus, to 11 mm in height; fusiform and elongate. Aperture narrowly ovate; columellar lip erect anteriorly, appressed posteriorly, with two small folds extending into the aperture at the anteriormost end; anal notch deep and narrow; outer lip slightly crenulated, with five denticles on inner side, all approximately of same size. Spire high, protoconch of one and one-half keeled whorls; six postnuclear whorls. Suture indistinct, body whorl with 12 or 13 flattened axial ribs; only other axial ornament fine growth laminae. Spiral ornamentation of, on spiral whorls four, and on body whorl usually nine major cords: six on body and three on siphonal canal; other spiral sculpture consisting of three beaded threads between each pair of major cords; at intersection of axial ribs and spiral cords, elongate, flattened nodes developed. Siphonal canal short, narrowly open. Shell color white, tops of each axial rib marked with dark reddish-brown, except along a zone paralleling the two spiral cords that number fourth and fifth anterior to the suture; here only the tops of the nodes colored, giving the illusion of a lighter colored band encircling the shell at the base of the body whorl. Aperture white.

Lectotype: MNHN (here designated), specimen figured by Fischer-Piette, 1942, pl. 7, fig. 10.

Dimensions of lectotype: Height 10.2 mm, diameter 4.2 mm.

Type of locality: Ile de Gorée, Senegal, West Africa.

Figured specimens: Fig. 4, USNM 859067; height 9.9 mm, diameter 4.0 mm. Fig. 5, MNHN (paralectotype); height 10.8 mm, diameter 4.5 mm. Locality of both: Ile de Gorée, Senegal.

Discussion: Adanson (1757, p. 132) recognized that there are two similar species occurring together in Senegal; accordingly, he denominated one "Le Loset" and the other "Le Suga." He noted that the two were frequently seen together but that they could be distinguished by the shell of "Le Suga" being smaller, with fewer rows of tubercules, which are smaller, more inflated, and more distinct from each other. The color is also different.

Initially, Fischer-Piette (1942, p. 229) in his study of the mollusks of Adanson, agreed with this assessment, giving the name "*Tritonalia*" *suga* to the Adanson species, which had never received a Linnean name. But subsequently Fischer-Piette and Nicklès (1946, p. 61) reduced the taxon to the rank of a variety of "*T.*" *fusiformis*, stating that Nicklès had collected a number of specimens, which permitted discovery of the transition between "Le Loset snd "Le Suga."

However, we are convinced that Adanson was correct in his evaluation of these two forms. The distinctions cited by Adanson are valid and "Le Suga" may indeed be distinguished by its smaller, narrower shape, fewer rows of tubercles and by the color, which is strikingly different from that of *M. fusiformis*. In coloration it is most nearly like the species from South America: *M. gilbertharrisi*, *M. withrowi*, and *M. necocheanus*, all of which have a light-colored shell with dark-brown tubercules. It differs from the American forms, however, in its smaller size (maximum height less than 11 mm) and narrower outline. Also, it lacks the one greatly enlarged denticle on the inner side of the outer lip; all of the denticles are approximately of the same size.

In the type lot there are 12 specimens. One of these was figured by Fischer-Piette (1942, pl. 7, fig. 10) and this same shell was later cited by Fair (1976, pl. 22, fig. 332) as "holotype." However, nowhere did Fischer-Piette mention that it was a type, but it was figured only as "un exemplaire X 2." Therefore, we here designate this specimen as lectotype. The shell shown herein (pl. 4, fig. 5) was selected for figuring because it has a better aperture and stronger color. Neither example has a well-preserved protoconch (in fact, none in the type lot does), so another specimen is illustrated, showing that the protoconch is typical of the *Risomurex* group.

All material seen has come from Ile de Gorée, most from the rocks, but the specimen with protoconch came from a lot dredged at 25 m (no doubt the reason it had a well-preserved protoconch). Knudsen (1956, p. 26) indicated that his specimens from "Station 38, Porto Grande, St. Vincent, Cape Verde Islands" should be referred to "variety *suga*." However, the example he figured from "Station 38" is *Trachypollia nodulosa*, as noted above, and there is no other evidence that *M. suga* occurs in the Cape Verde Islands.

MURICOPSIS (RISOMUREX) GALBENSIS (Jung)
Plate 2, fig. 6

Risomurex galbensis JUNG, 1969, Bulls. Amer. Paleontology, v. 55, no. 247, p. 495, pl. 50, fig. 10-13.

Description: "Small, stout. Protoconch consists of a little less than 1-1/2 smooth whorls. It is strongly keeled and flattened above forming a depression at the apex. Postnuclear whorls about five. Early sculpture consists of axials (about 10 on first scuptured whorl) and two spirals form beads at the intersections. On subsequent whorls the axials become much stronger, and the upper spiral forms a shoulder with acute nodes, where the axials cross. On the second or third sculptured whorl another spiral appears close to the lower suture which is noded as well. Spaces between spirals ornamented by several fine spirals. Body whorl with six to seven noded spirals and eight axials, the last ones being varix-like. Unworn specimens show undulating, somewhat lamellar growth lines. Outer lip thick, with five denticles on inner surface. Inner lip with two inconspicuous lirae on lower part. Anterior canal short. Siphonal fasciole inconspicuous." (Jung, 1969)

Holotype: USNM 645367.

Dimensions of holotype: Height 13.8 mm, diameter 7.7 mm.

Type locality: Courbaril Sand Member, Morne l'Enfer Formation, Pt. Courbaril, Trinidad.

Figured specimen: USNM 645367 (holotype).

Discussion: The Courbaril Sand fauna, according to Jung (1969, p. 306), represents a near-shore environment, with many examples of *Diodora, Cerithium, Bittium*, and some 50 examples of mostly worn

Muricopsis galbensis. It is thought to be Early Pliocene in age.

Although Jung compared his species with the other Caribbean members of *Risomurex*, it most nearly resembles the more southern (Brazil and Argentina) *M. necocheanus*, which has smaller labral denticles and weaker spiral ornamentation. As is noted below, *M. necocheanus* differs from the other species of *Risomurex* in lacking the keeled protoconch, which *M. galbensis* does have, suggesting that perhaps it is an intermediate form between the tropical, typical *Risomurex* group and the more southerly *M. necocheanus*.

MURICOPSIS (?RISOMUREX) NECOCHEANUS
(Pilsbry)
Plate 2, fig. 10

Sistrum nicocheanum [*sic*] PILSBRY, 1900, Nautilus, v. 14, p. 3.

Morula necocheana (Pilsbry). RIOS, 1970, Coastal Brazilian Seashells, p. 81, pl. 24; 1975, Brazilian Marine Mollusks Icon., p. 92, pl. 27, no. 381.

Muricopsis nicocheanus (Pilsbry). RADWIN and D'ATTILIO, 1976, *Murex* Shells of the World, p. 169, pl. 23, fig. 12.

Description: Shell large for the subgenus, to 25 mm in height; elongate fusiform. Aperture ovate; columellar lip erect anteriorly, adherent above, with two elongate plaits anteriorly, extending into the aperture; anal notch large and moderately deep; outer apertural lip shallowly crenulate, bearing five or six denticles on the inner side, second (or third when six denticles present) denticle slightly larger than the others. Spire high; six slightly convex postnuclear whorls and a protoconch of undetermined nature. Suture impressed. Body whorl with six or seven strong rounded axial ridges, no other axial sculpture. Spiral sculpture consisting of eight low cords, more apparent on the axial ridges; one cord on the shoulder, five on the body and two on the siphonal canal; three or four intermediate threads between each pair of spiral cords. Siphonal canal short, narrowly open and slightly recurved dorsally. Shell color light or dark brown, with darker markings on top of the spiral cords, at the intersection with the axial ridges; aperture white, sometimes surrounded with a light brown line.

Lectotype: ANSP 72640 (here designated).

Dimensions of lectotype: Height 21.5 mm, diameter 11.0 mm.

Type locality: "Nicochea" [Necochea], Argentina.

Figured specimen: Vokes Collection; height 19.4 mm, diameter 9.8 mm; locality, Cabo Frio, Brazil.

Discussion: According to Rios (1975, p. 92) this species occurs on rocky bottoms from Espirito Santo, in central Brazil, to Bahia Blanca, Argentina. The type locality is Necochea, which is between Bahia Blanca and Mar del Plata in northern Argentina. Although the original spelling was as "*nicocheanum*," this is an error and, according to ICZN Code, Article 32a(ii), is to be emended.

The decision to include this species as a *Risomurex* is something of a compromise. The characters that would place it in *Muricopsis* s.s. include no very large apertural tooth and a rounded rather than keeled protoconch, as best can be determined from the material at hand, all of which is eroded. However, if the lack of distinct varices is considered to be the most critical distinction between *Muricopsis* and *Risomurex*, then *necocheanus* should be placed in the latter. The principal reason, however, for placing it here is the strong resemblance to the fossil *M. crassicosta*, which also lacks the keeled protoconch, but has the large apertural tooth, and the similarity of the color pattern to that of the Recent *M. withrowi*, with dark spiral cords topping the axial ridges.

The type lot of "*Sistrum nicocheanum*," in the collections of the Academy of Natural Sciences of Philadelphia, consists of eight specimens, all extremely beachworn. Only one of these, the largest, matches the measurements cited by Pilsbry (height 21.5 mm, diameter 11 mm); accordingly, it is here designated as lectotype. The other seven paralectotypes now bear the museum number ANSP 359103.

MURICOPSIS (RISOMUREX) CRASSICOSTA
(Benoist)
Plate 3, figs. 6, 7

Jania crassicosta BENOIST, 1873, Cat. Saucats, p. 349.

Janiopsis crassicosta (Benoist). COSSMANN, 1901, Essais Paléoconch. Comp., v. 4, p. 178.

Muricopsis crassicosta (Benoist). COSSMANN and PEYROT, 1923, Linn. Soc. Bordeaux, Actes, v. 75, p. 142, pl. 15, fig. 5 (said to also be fig. 6, but not there).

Description: Shell large for the subgenus, to 21 mm in height; solid and heavy. Aperture ovate and narrow; columellar lip with two elongate nodes anteriorly; anal notch moderately deep; outer apertural lip crenulate, five strong denticles on the inner side, the second being the

strongest. Spire high; protoconch of one and one-half rounded whorls; eight or nine slightly angulate postnuclear whorls. Suture impressed, undulated by axial ridges. Body whorl with eight heavy, low axial ridges, crossed by eight or nine spiral cords: one on the shoulder, five or six on the body, and two on the siphonal canal; between each pair of major cords two fine squamose threads. At the intersection of the spiral cords and axial ridges low, elongate nodes developed; spiral cords forming five or six short spines on apertural varix. Siphonal canal open, short, wide and slightly recurved dorsally.

Neotype: Cossmann Collection, Dept. de Paléontologie, Université Paris (VI).

Dimensions of neotype: Height 21 mm, diameter 10 mm (*fide* Cossman and Peyrot, 1923, p. 143).

Type locality: Saucats (about 25 km south of Bordeaux), France.

Figured specimens: Fig. 6, USNM 377394, height 17.3 mm, diameter 9.4 mm; locality, Saucats, France. Fig. 7, USNM 377395; height 16.0 mm, diameter 8.5 mm; locality TU 555.

Discussion: In the Chipola Formation of northwestern Florida there are rare examples (seven in all, from TU 555, 547, and 1048) of a *Muricopsis* that proves to be identical to the species cited by Cossmann and Peyrot (1923, p. 142) as *Muricopsis crassicosta* (Benoist). Unfortunately, Benoist did not figure his species, but as the form is common in the Burdigalian Miocene of France, especially at Saucats, it is presumed that their identification is correct.

The confusion of this species with the members of *Janiopsis*, which is a buccinid, was caused by the presence of the labial denticles and the non-varicate shell. These same characteristics also apply to *Risomurex*; however, the species does not have a keeled protoconch. As noted under *M. necocheanus*, if the lack of distinct varices is considered as a more important taxonomic character than the keeled protoconch, then *M. crassicosta* may be placed with no difficulty in *Risomurex*. As there are species of *Muricopsis* that have a keeled protoconch, this character cannot be restricted to the subgenus. Therefore, it seems probable that the unkeeled protoconch of *M. crassicosta* and *M. necocheanus* is the primitive condition and *M. crassicosta* is the ancestor of the *Risomurex* line.

Because of the morphological similarity between *M. crassicosta* and the South American species of *Risomurex*, all of which have a color-pattern consisting of darker nodules on a light-colored shell, the examples of *M. crassicosta* were subjected to soaking in household bleach (sodium hypoclorite) and photographed under ultra-violet light. Happily, the color pattern proved to be almost identical to the living specimens (as may be seen in pl. 3, fig. 7b).

V. SUPPLEMENTARY LOCALITY DATA

The following are Tulane University fossil localities:

555. Chipola Fm., east bank of Chipola River, about 1000 ft. above Four Mile Creek (SW 1/4 Sec. 29, T1N, R9W), Calhoun Co., Florida.
547. Chipola Fm., west bank of Chipola River, about 2000 ft. above Four Mile Creek (SW 1/4 Sec. 29, T1N, R9W), Calhoun Co., Florida.
1048. Farley Creek, south bank, about 0.8 mi. east of bridge of Florida Highway 275 (NE 1/4 Sec. 21, T1N, R9W), Calhoun Co., Florida.

The following are Tulane University Recent localities:

R-109. Fill for refinery, Bahia las Minas, Isla Payardi, Panamá. (Radiocarbon dated at 7000 years B. P.)
R-366. Punta Cahuita, 42 km southeast of Puerto Limón, Costa Rica.
R-389. Monte Cristi, beach near foot of mountain, at north side of town, Prov. of Monte Cristi, Dom. Rep.

VI. APPENDIX – COMMENTS ON THE GENUS *MURICOPSIS* s.s.

The type species of *Muricopsis* is the Mediterranean *"Murex" blainvillei* Payraudeau, 1826. It is closely related to a form originally named from the Plio-Pleistocene of Italy as *"Murex" cristatus* Brocchi, 1814. There is considerable doubt if the two taxa actually represent two biologically distinct species. On the whole, the fossil shells are larger (attaining a usual height of 35-40 mm), more scabrous, with a proportionally longer siphonal canal. The Recent *M. blainvillei* is less scabrous, and has a smaller, broader shape (usual height no more than 25 mm). But both types occur in the Recent Mediterranean fauna. The living form referred by authors to *M. cristatus* has a larger light-colored shell in contrast to the smaller, darker shell usually referred to *M. blainvillei*. Fair (1976, pl. 17, figs. 232, 233) shows both types and a typical example of the living *M. cristatus* was

figured by Radwin and D'Attilio (1976, pl. 23, fig. 14). Although the latter was mistakenly identified in the plate explanation as "*Muricopsis blainvillei*," in the text (*ibid.*, p. 167) the shell is indicated as being thought to be the type of *Murex cataphractus* Sowerby, 1834, a synonym of *M. cristatus*.

Comparison of numerous examples of both forms does not reveal any consistent differences, other than size and color. The protoconchs of both are identical one and one-half rounded whorls, but on the basis of a very limited sample (most specimens are decollated) the protoconch of the *cristatus* form is slightly larger than that of the *blainvillei* form; this may be a reflection of the overall larger size.

It is presumed that the two extremes represent end members of a single cline, which is in the process of changing through time. As the name "*blainvillei*" is so entrenched in the literature, it would be unwise to suggest that the two names be synonymized without more solidly based biological evidence to back up the assumption.

It might seem that the strongly keeled protoconch seen in the species of *Risomurex* could be considered as diagnostic for the subgenus; however, *Muricopsis pauxillus* and *M. jaliscoensis* also have keeled protoconchs. So far as known, all other species of *Muricopsis* s.s. have rounded protoconchs.

A list of Recent species of *Muricopsis* s.s. recognized by us would include:

armatus (A. Adams, 1854) [*Murex*]; West Mexico.

blainvillei (Payraudeau, 1826) [*Murex*] (which may prove to be a synonym of *M. cristatus*); plus a number of named "varieties," probably all synonyms; Mediterranean.

cristatus (Brocchi, 1814) [*Murex*]. As noted above, there is some question as to whether *blainvillei* and *cristatus* should be separated at all, or perhaps treated as stratigraphic subspecies, with the name *cristatus* applied only to the Plio-Pleistocene members. if synonymized this is the older taxon.

cuspidatus (Sowerby, 1879) [*Murex*]; Indo-Pacific.

huberti Radwin and D'Attilio, 1976; Lesser Antilles.

jaliscocensis Radwin and D'Attilio, 1970; West Mexico.

oxytata (M. Smith, 1938) [*Murex*] Florida and Caribbean, including Gulf of Mexico.

pauxillus (A. Adams, 1854) [*Murex*]; West Mexico.

radula (Hedley, 1899) [*Murex*] (not *M. radula* Linné); Ellice Islands. The sole sample is an immature shell, with an incomplete outer lip; but it seems referable to *Muricopsis*. It has no valid name that we are aware of.

tulensis Radwin and D'Attilio, 1976, West Mexico.

zeteki Hertlein and Strong, 1951; West Mexico to Ecuador, including Galápagos Islands.

The following species have been referred, at one time or another (chiefly Vokes, 1971) to the genus *Muricopsis*, but are better placed elsewhere.

angolensis (Odhner, 1922) [*Ocenebra*]. Examination of the type material above shows this species is a synonym of *Orania fusulus* (Brocchi)*; however, the specimen figured by Radwin and D'Attilio (1976, pl. 27, fig. 11) is not *angolensis* but *M. (Risomurex) rutilus* (Reeve) (see above).

bombayanus (Melvill, 1893) [*Murex*]. The operculum with a sublateral nucleus, plus the overall shell color and ornamentation, indicate placement in *Lataxiena*.

brachys (Melvill and Standen, 1869) [*Murex*]. Fair (1976, figs. 236, 236A) and Cernohorsky (1983, fig. 6) have both figured the holotype of *Murex brachys*. It is a synonym "*Ricinula*" *echinata* Reeve, 1846, as noted by Cernohorsky, but it is neither a *Muricopsis* nor a *Morula*, rather it is to be referred to the Ergalataxinae in an as yet undetermined genus.

brazieri (Angas, 1878) [*Murex*]. Is a *Murexsul*. The specimen figured by Radwin and D'Attilio (1976, pl. 24, fig. 13) as "*Muricopsis brazieri*" is *Murexsul purpurispina* (Ponder).

caledonica (Jousseaume, 1881) [*Muricidea*]. Is an *Attiliosa* (see Vokes and D'Attilio, 1982, p. 70).

infans (E. A. Smith, 1884) [*Murex*]. The holotype of this species (figured by Fair, 1976, pl. 17, fig. 228, and Kaicher, 1980, no. 2560) shows that it is an *Ergalatax*. The species described and figured by Radwin and D'Attilio (1976, p. 168, pl. 3, fig. 3) is not *M. infans* but *Muricopsis orri* Cernohorsky 1976 (see below).

iostomus (A. Adams, 1853) [*Murex*] (not *M. ios-*

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*The specific name "*fusulus*" is a noun - little spindle - and does not change to agree with the feminine *Orania*. The type of the genus *Orania* is *Murex spadae* Libasse, 1859, which has usually been considered to be a member of the Corallipphilidae; however, *Murex fusulus* Brocchi, 1814, is a synonym of *M. spadae* and has a radula that indicates placement in the muricid subfamily Ergalataxinae.

toma Sowerby, 1834); Philippine Islands. The type has been figured by Kaicher (1980, no. 2457), and it is to be referred to *Spinidrupa*. It has no valid name that we are aware of.

medicago (Watson, 1897) [*Murex*]. Is a synonym of *M. aradasii* Monterosato *in* Poirier, 1883, and is a *Murexsul*. Fair (1976, pl. 17, fig. 244) has illustrated the type of *medicago*.

nitens (A. Adams, 1854) [*Murex*]. Is an *Ergalatax*, Fair (1976, pl. 17, fig. 235) and Kaicher (1980, no. 2594) have illustrated the type.

noduliferus (Sowerby, 1841) [*Murex*]. Referred to *Attiliosa* by Vokes and D'Attilio (1982, p. 70).

oliverai (Kosuge,1984) [*Muricopsis*]. Should be referred to *Pazinotus* (see Vokes, 1985).

orri Cernohorsky, 1976 [*Muricopsis*]. A species only recently named (Cernohorsky, 1976, p. 116, figs 12-20) in the genus *Muricopsis*, and subsequently transferred to *Attiliosa* by Vokes and D'Attilio (1982, p. 71).

purpurispina Ponder, 1972 [*Muricopsis*]. Ponder considered the genera *Muricopsis* and *Murexsul* synonymous when he named this new species (1972, p. 242, pl. 23, fig. 6; text fig. 3:28 - radula). We do not accept this assignment and consider it better placed in *Murexsul*. As noted above, this species was figured by Radwin and D'Attilio as "*Muricopsis brazieri*."

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July 31, 1986

A NEW SPECIES OF *MURICOPSIS (RISOMUREX)* FROM WEST AFRICA

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After the accompanying paper (Vokes and Houart, 1986) was completed, another new species of *Risomurex* was discovered on the coast of Senegal. Because of its relevance to the aforementioned work, it seems appropriate to describe it here.

MURICOPSIS (RISOMUREX) SEMINOLENSIS
Vokes and Houart, n. sp.
Text figs. 1-3

Description: Shell small for the subgenus, from 9 to 11 mm, elongate and fusiform. Aperture narrow and ovate. Columellar lip erect anteriorly; smooth, except two small folds on its anterior part. Anal notch deep and wide. Outer lip undulate; inner part of outer lip bearing five or six strong denticles; third denticle (or second when only five denticles present) strongest; others much smaller. Spire high and acute, consisting of one and one-half to one and three-quarters strongly keeled nuclear whorls and five to six elongate postnuclear whorls. Suture impressed. Body whorl with seven or eight strong nodulose axial ridges. Spiral sculpture consisting of ten or eleven major cords: two or three small on the shoulder; five strong on the body with one shallow intermediate thread; three other strong cords on the siphonal canal. Intersection of axial ridges and spiral cords giving a nodulose appearance to the shell. Siphonal canal short, narrowly open, slightly backward bent. Color ochre to light brown, stained with

dark brown on the axial ridges, mostly on the shoulder. Third, fourth and fifth spiral cords on the body sometimes darker, forming a dark band.

Holotype: Muséum National d'Histoire Naturelle, Paris.

Dimensions of holotype: height 8.5 mm, diameter 4.0 mm.

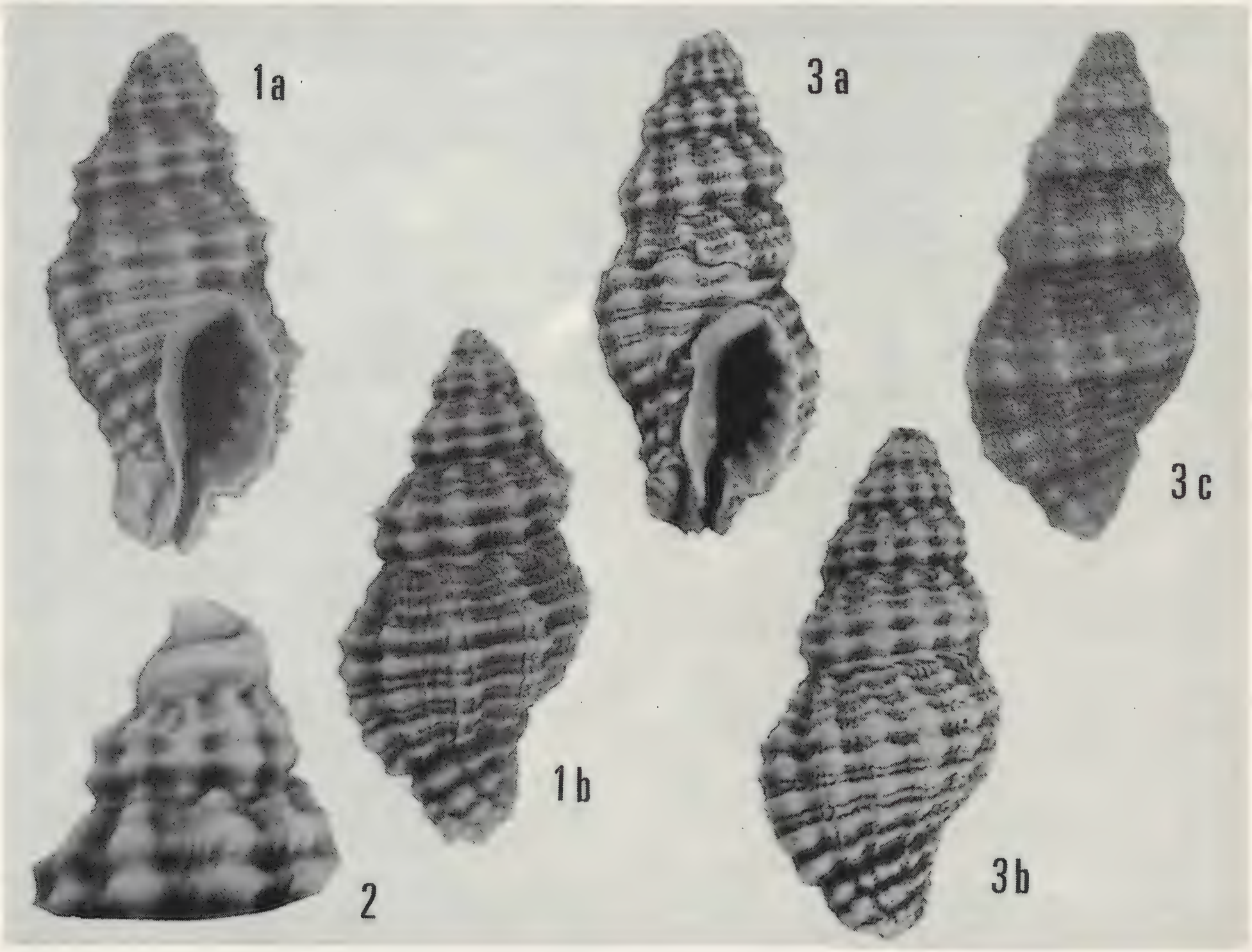
Type locality: Banc du Seminole, 38 meters, off Dakar, Senegal. Coll. Marche-Marchad.

Other material studied: 12 paratypes, MNHN, Paris; 1 paratype, Zoologisk Museum, Copenhagen, Denmark.

Discussion: This is the fourth known *Risomurex* species from western Africa. It may be compared with *R. rutilus* (Reeve, 1846) but differs in many aspects: the shell is narrower with more spiral cords; *R. rutilus* has only one spiral cord on the shoulder and shows two or three intermediate threads between body spiral cords; the aperture of *R. rutilus* is more elongate and larger, it has a straighter and more adherent columellar lip. *Risomurex suga* (Fischer-Piette, 1942) is a narrower, more elongate and rounded shell with smaller, more numerous dark brown colored axial ridges. *Risomurex fusiformis* (Gmelin, 1791) is a larger and wider shell. It is more fusiform, with a larger aperature, bearing weaker denticles. The axial ridges and the spiral cords are smaller and more numerous.

We wish to thank Dr. Philippe Bouchet, Muséum National d'Histoire Naturelle, Paris, for the type material.

July 31, 1986



Figures 1-3. *Muricopsis (Risomurex) seminolensis*, n. sp. 1, Holotype, MNHN; height 8.5 mm, diameter 4.0 mm; Banc du Seminole, 38 meters, off Dakar, Senegal (x 6). 2, Paratype A, MNHM; height 6.6 mm, diameter 4.4 mm; locality same as holotype (x 20). 3, Paratype B, MNHN; height 11.0 mm, diameter 4.9 mm; off Dakar, Senegal (x 4). All specimens whitened except 3c.

REVIEWS

Barton, Benjamin Rush, and other early Philadelphia scientists, through Henry Darwin Rogers (the first Professor of Geology and Mineralogy), J. Peter Lesley, Ferdinand Vandiveer Hayden, Joseph Leidy, Edward Drinker Cope, and many others associated both with the university and other Philadelphia institutions such as the Academy of Natural Sciences and Charles Willson Peale's museum. The section concludes with A Chronology from Mohole to JOIDES, a review of the major progress during the past three decades in exploring the nature of the Earth's interior by studying the floors of the oceans ("The ocean's bottom is at least as important as the moon's behind").

The seven papers in the final segment of this volume, *Application of Significant Ideas*, include North American Paleomagnetism and Geology, sketching the developments in this field which have led to a magnetic time scale based on the chronology of field reversals and other discoveries which have markedly affected current geological thought; the Early Development of Archaeological Geology in North America; the Anticlinal Theory of Oil and Gas Accumulation; Application as Stimulus in Geology; Seismic Exploration of the Crust and Upper Mantle of the Basin and Range Province; The Development of Earthquake Seismology in the Western United States; and, Geology from Space, A Brief History of Orbital Remote Sensing. This last section helps to place the historical development of geological thought into current perspective.

The historical importance of this Centennial Volume cannot be overstated. It comprises a most refreshing review of many aspects of the development of both practical and theoretical geology and serves to place these factors into their proper historical perspective, and provides a base for comprehending the limitless scope of geological investigation as we near the final decade of the twentieth century. This volume should be welcomed by all functioning geoscientists and deserves a convenient place on our reference shelves.

THE MARINE BENTHIC DIATOMS IN CHINA, Volume I, by Jin Dexiang (T. G. Chin), Cheng Zhaodi, Lin Junmin, and Liu Shicheng. Published by China Ocean Press, Beijing, China, and distributed by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, x + 313 pp., illus., atlas of 67 pls., $99.50

Work on marine diatoms in China is unfamiliar to western readers because of the language barrier and *The Marine Planktonic Diatoms in China* (1964, in Chinese) is the only previous book-length work on this subject. The present volume is the first of three planned and intended to survey the knowledge of marine diatoms along the coasts of China for the English-reading scientist. They will supplement but not fully duplicate the diatoms reported in the earlier work in Chinese, and may be considered a continuation of that work. In this first volume, 445 species and varieties from the Fujian Coast and vicinity are presented. The second volume will deal with diatoms from the South China Sea, and the third with those from the other waters along the coasts of China.

This book describes diatoms principally from the intertidal zones, but those from brackish and inland fresh waters also are included, together with some diatoms from sediments of the continental shelf and slope of the East China Sea and the Okinawa Trough. Only the most important or major species are covered in this volume, with only names and additional descriptions given for those reported in the previous volume (in Chinese).

Aside from a brief introduction and a short treatment of the Taxonomical System of Diatoms which includes the rudiments of classification and a Key to the Representative Genera in Each Family and the Common Genera in China, this book is an illustrated and descriptive catalog of species from Chinese Coastal Waters. Though somewhat limited and difficult to use, it will be useful to paleontologists working with diatom assemblages throughout the world.

—H.C.S.

NEW SPECIES OF *BATHYSIPHON* (FORAMINIFERIDA: TEXTULARIINA) FROM FRANCISCAN FLYSCH DEPOSITS, NORTHERNMOST CALIFORNIA

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Macroscopic invertebrate fossils are exceedingly rare in sedimentary rock units of the Franciscan Complex. A few occurrences of *Buchia* bivalves and ammonoid cephalopods have been reported (Bailey *et al.*, 1964, p. 115-124), but these could be transported faunal elements. Microfossils are fairly common, although they occur in isolated localities within a tectonically scrambled terrain of sedimentary units, greenstone blocks, and melange (Blake and Jones, 1974). The only unequivocally indigenous macrofaunal remains preserved in Franciscan sedimentary sequences are trace fossils, represented by locally diverse and abundant assemblages of previously unreported *Nereites* Ichnofacies forms (Miller, 1986).

In the course of a field search for examples of these newly discovered Franciscan trace fossils at Point Saint George, Del Norte County (Fig. 1), several specimens of the large, benthic foraminiferid, *Bathysiphon*, were collected. They occur at the bases of turbidite beds that feature Bouma T_{cde} and T_{de} divisions. These beds probably were deposited by intermittent turbidity currents on the distal, lower lobe of a submarine fan (see Walker and Mutti, 1973). Like the majority of the previous finds of Franciscan macrofossils, the specimens of *Bathysiphon* are, in all likelihood, transported. The geologic context of the fossil locality at Point Saint George has been described by Aalto and Murphy (1984). All specimens are deposited in the U. S. National Museum of Natural History (USNM), Washington, D. C.

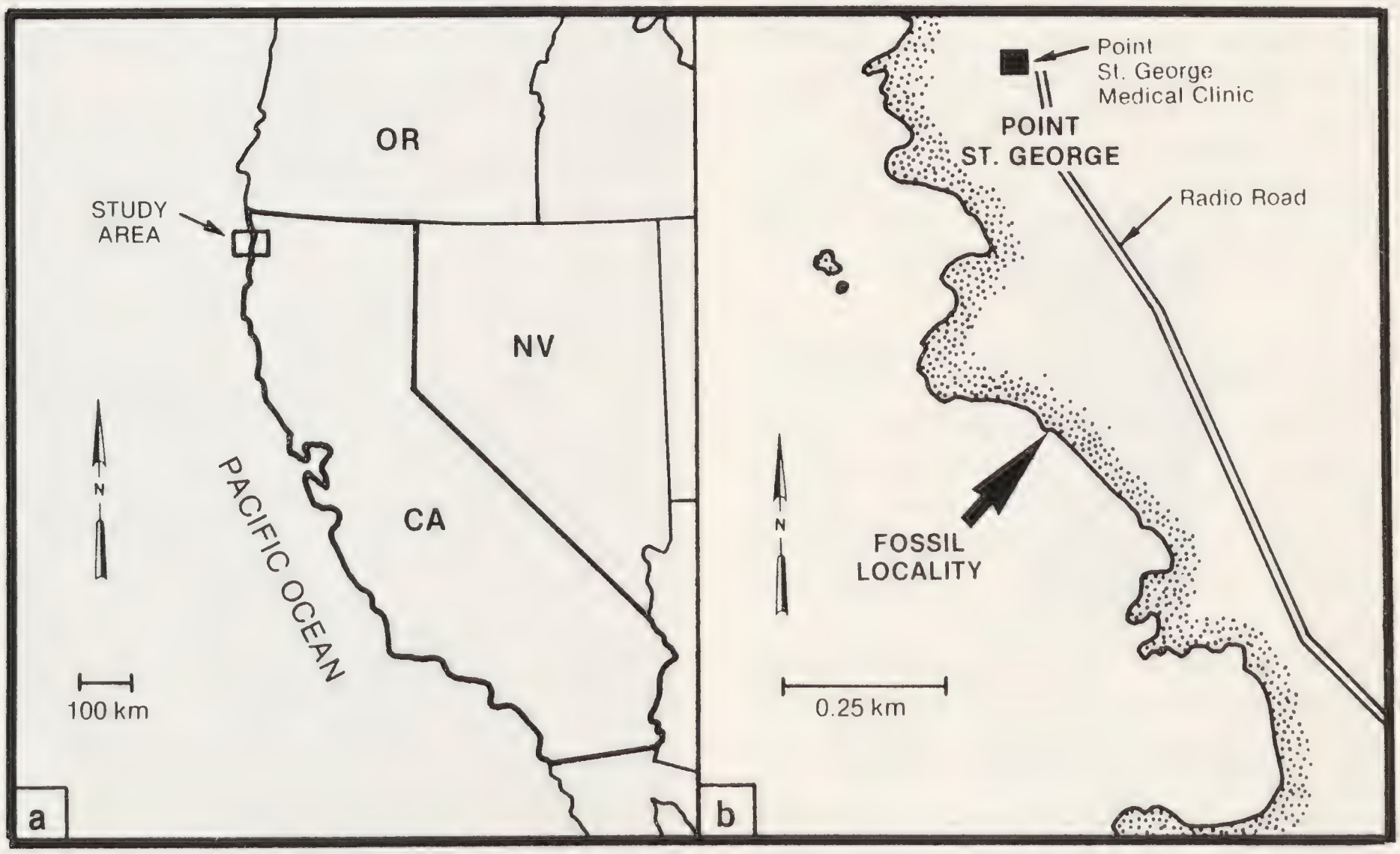

Figure 1. a) Index map showing general location of collecting area in northernmost California; b) Detail of the area near Point Saint George, coastal Del Norte County.

Order FORAMINIFERIDA
Eichwald, 1830
Suborder TEXTULARIINA Delage and Hérouard, 1896
Superfamily AMMODISCACEA
Reuss, 1862
Family ASTRORHIZIDAE Brady, 1881
Subfamily RHIZAMMININAE
Rhumbler, 1895
Genus BATHYSIPHON M. Sars
in G. O. Sars, 1872
BATHYSIPHON AALTOI W. Miller, III, n. sp.
Figs. 2, 3

Description: Test free, large, elongate, and elliptical in cross-section; wall thick, siliceous, apparently composed of sponge spicules aligned subparallel to one another on the exterior surface in an overall axial orientation; cross-sections through wall showing either a weakly developed arrangement of radial silica fibers or structureless, translucent silica; test with weak annular constrictions, and an axial crease accentuated in collapsed test segments, forming a strong axial fold in deformed specimens.

Greatest outer diameter observed: 4.5 mm; average outer diameter (N = 5): 3.3 mm; greatest exposed segment length: 9 mm; thickness of walls: 0.5-1.0 mm.

Syntypes: USNM 399552 (Fig. 2a); USNM 399553 (Fig. 2b); USNM 399554 (Fig. 2c, B_1); USNM 399555 (Fig. 2c, B_2); USNM 399556 (Fig. 2c, B_3).

Type locality: Franciscan Complex, Late Mesozoic Central Belt; in ocean cliff exposing interbedded dark gray shale and olive sandstone, 0.5 km south of private medical clinic (old U. S. Coast Guard station) on Point Saint George, in area mapped as "Faulted Facies D" by Aalto and Murphy (1984, Fig. 3); west side of Radio Road, Del Norte County, California (Fig. 1b).

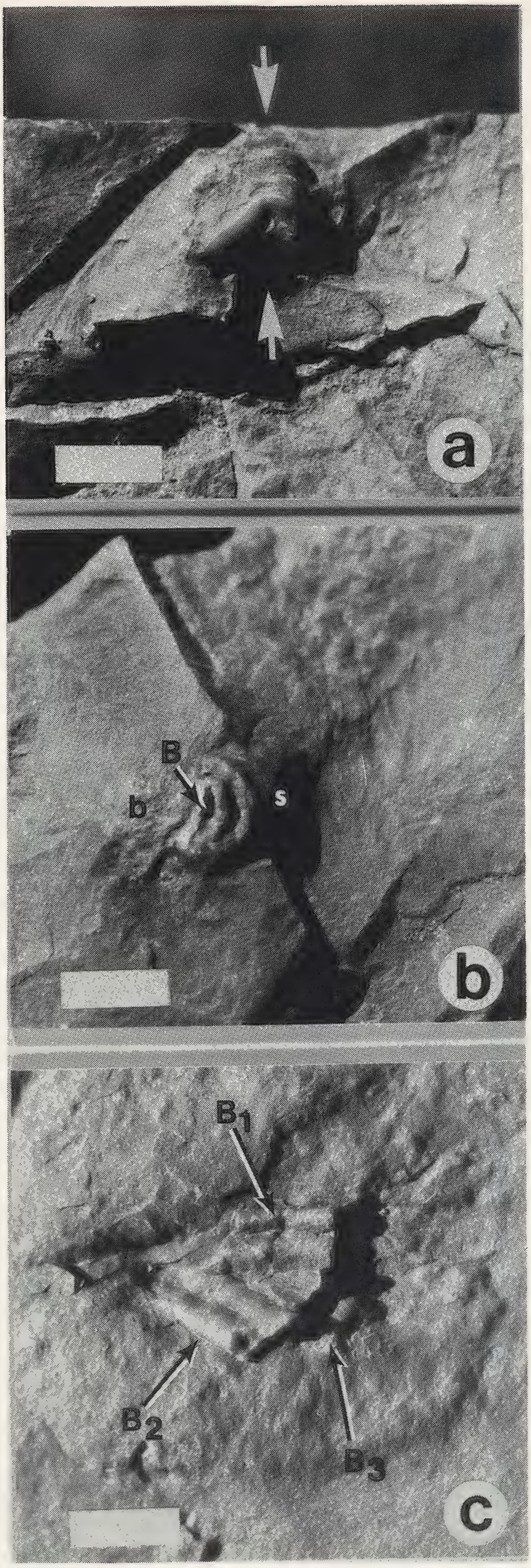

Figure 2. a) Specimen of *Bathysiphon aaltoi* (USNM 399552) on sole of turbidite bed (note broken section through siliceous test, and position of segment at oblique angle to bedding that is parallel to plane of the photograph); b) Specimen of *B. aaltoi* (B in photograph, USNM 399553) on the sole of a turbidite bed, with associated sleeve of argillaceous sediment (s) and a post-depositional burrow (b); c) Cluster of three *B. aaltoi* test segments (B_1, USNM 399554; B_2, USNM 399555; B_3, USNM 399556) associated with flute or tool mark on the sole of a turbidite bed (note axial crease in the two upper specimens). All bar scales represent 5 mm.

Discussion: The specimens of *B. aaltoi* are similar to *B. carapitanus* Hedberg, 1937, from the Tertiary Carapita Formation of Venezuela, and especially to *B. sakuensis* Asano, 1950, described from the Cretaceous Saku Sandstone, Hokkaido Island, Japan. They differ, however, in certain key respects: (1) both *B. aaltoi* and *B. carapitanus* have tests with annular constrictions and an axial furrow, but *B. carapitanus* features annulations that are much more strongly developed, and the test is smaller in size with finely arenaceous walls; (2) *B. aaltoi* is much closer in general appearance and size to *B. sakuensis*, but the latter also constructs its wall from fine sand or structureless siliceous material. *Bathysiphon aaltoi* appears to be unique among contemporary species of its genus in having an external wall with discontinuous, parallel, microscopic ridges arranged in an axial orientation (probably incorporated sponge spicules), and in having internal wall microstructure that in some instances comprises radial fibers of silica. The large test size, tubular shape, axial crease, annular constrictions, and light gray siliceous wall material would make *B. aaltoi* especially distinctive in field identifications.

This new foraminiferid is named in honor of Dr. Kenneth R. Aalto (pronounced *ȯl'-tō*), expert on the structure, sedimentary petrology, and geologic history of the Franciscan Complex in northern California, and Associate Professor in the Department of Geology, Humboldt State University.

Occurrence and significance: All specimens were collected from the bases of turbidite sandstone or siltstone beds within a sequence of Facies D flysch deposits (terminology of Walker and Mutti, 1973, p. 132). These sediments accumulated in overbank, lower suprafan lobe, or perhaps even adjacent deep-ocean basin floor depositional environments. All specimens were segmented and folded lengthwise to a greater or lesser degree. All occurred embedded at oblique angles to bedding (Fig. 2), and one cluster of three test segments was associated with what seemed to be tool or flute casts (Fig. 2c). These characteristics indicate that *B. aaltoi* was transported to the deep-water flysch environment of an active submarine fan. Whether transportation was from a proximal, upslope area within the fan complex, or from a distal, continental margin source, is not known.

Knowledge of the fossil record of Franciscan sedimentary units is very poor, so that any new report of macroscopic fossil remains, indigenous or exotic, is of special interest. The distribution of *B. aaltoi* is currently unknown, but its biostratigraphic potential as a zonal guide fossil should be carefully evaluated through further collecting. If the segments of *B. aaltoi* have been transported from benthic communities on the fan lobes, they provide a glimpse of the indigenous Franciscan deep-water fauna, which is represented for the most part by *Nereites* Ichnofacies trace fossils. One important aspect of finding *B. aaltoi* is to dispel the widely held notion that Franciscan rocks are unfossiliferous. Although these tectonically dismembered sedimentary blocks are never rich in shelly fossil beds, they do contain a localized, unique fauna and ichnofauna that indicate special conditions of life, death, and preservation on the deep-sea floor. Fossils such as *B. aaltoi* have potential as paleoenvironmental and biostratigraphic guides in a lithodemic unit in which the fossil record has been largely overlooked.

Figure 3. Reconstruction of a typical segment of *Bathysiphon aaltoi*.

I thank Dr. Kenneth R. Aalto for showing me the fossil locality at Point Saint George and for many stimulating conversations on Franciscan rocks, Dr. Emily H. Vokes for adroit editorship, and Ms. Sandi Potter for preparing the locality map.

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July 31, 1986

REVIEW

THE UTILITY OF REGIONAL GRAVITY AND MAGNETIC ANOMALY MAPS, edited by William J. Hinze. Published by the Society of Exploration Geophysicists, Tulsa, Oklahoma, 1985, xiv + 454 pp., 8 1/2 x 11 1/4 inches, illus. (some in color), index, $75.00

Making maps of the Earth's gravity and magnetic fields has a long and distinguished history as part of the study of structural and petrological variations within the lithosphere. Technological advances following World War II made efficient and precise gravity and magnetic mapping of extensive regions feasible. However, much of the vast amounts of gravity- and magnetic-anomaly data collected by industrial firms in mineral-resource exploration and other non-governmental agencies generally have not been available to the public. In the United States, publicly available data recently have been composited into new and improved country-wide gravity- and magnetic-anomaly maps. In 1975, the Society of Exploration Geophysicists and the United States Geological Survey jointly organized gravity- and magnetic-anomaly map committees to prepare anomaly maps of the United States. In late 1982, a revised Gravity Anomaly Map of the United States was published by the SEG, and the Composite Magnetic Anomaly Map of the Conterminous United States and the Magnetic Anomaly Map of Alaska were released by the USGS.

Small-scale versions of these maps are reproduced in color in the present volume together with the most recently published gravity- and magnetic-anomaly maps of Canada. In recognition of the publication of these national maps, and to illustrate the many uses of such maps, a series of special technical sessions was held at the 52nd Annual International Meeting of the SEG in Dallas, Texas, in fall 1982. Of the fifty-three papers presented in these sessions, thirty-three were prepared for publication and are published in this volume. Digital two-dimensional filtering can be employed to produce maps of selected attributes of the anomaly fields such as gradients, wavelength ranges, and strike directions. The importance of digital filtering in data analysis is demonstrated by the contents of this symposium, as most of the papers use some form of digital processing. These papers illustrate the wide use of digital data sets, ranging from broad crustal structure investigations to exploration for mineral resources. The editors envision the content of this work as a "benchmark from which we can expand the understanding of our Earth by improved regional anomaly maps and data sets, additional processing of regional digital-data sets by filtering and inversion, and enhanced integration of the anomaly data with available geological and collateral geophysical data." This book is well-designed and handsomely produced and should serve well the purposes for which it was prepared.

—H.C.S.

PALEONTOLOGICAL NOTE

PUBLICATION DATES OF HEILPRIN'S EXPLORATIONS ON THE WEST COAST OF FLORIDA

RICHARD E. PETIT and DRUID WILSON*
NATIONAL MUSEUM OF NATURAL HISTORY
SMITHSONIAN INSTITUTION

Angelo Heilprin's *Explorations on the west coast of Florida and in the Okeechobee wilderness, with special reference to the geology and zoology of the Floridian Peninsula* (hereafter referred to as *Explorations*) was published as Volume 1 of the Transactions of the Wagner Free Institute of Science of Philadelphia. The new taxa proposed by Heilprin in this work have been consistently cited in the literature as dating from 1887. The purpose of this paper is to show that most of the new taxa properly date from 1886.

In the library of the Division of Mollusks, National Museum of Natural History, there is a copy of the *Explorations* consisting of pages 65-127, with a title page bearing the full title of the work and the printed date of 1886. This copy also has a cover on heavier stock with the same printed matter as the title page. Between the cover and title page is inserted a printed tab with the legend "Pages 1-64, and the plates to accompany the report - unavoidably delayed - are in course of publication." Further internal evidence of this separate publication of the parts is seen in the final printing where two extra pages, numbered 64A and 64B, had to be inserted after the 4th signature (the 5th signature beginning with page 65), as a result of the text being longer than anticipated.

External evidence supporting the printed date of 1886 exists in a review of pages 65-127 published by Dall in 1886 (Dall, 1886, p. 2). The only correct bibliographic citation of the *Explorations* that we have been able to locate is that of Darton (1896, p. 468) who errs only in his substitution of *western* for *west* in the title.

Given these facts, it is obvious that pages 65-127 of the *Explorations* were printed and distributed in 1886 and that the new taxa on those pages should date from that year.

In 1887 the *Explorations* was issued in its entirety as Volume 1 of the Transactions of the Wagner Free Institute of Science of Philadelphia. The 1887 title page differs from the 1886 title page in two respects: the date of 1886 was changed to 1887, and the title of the paper was shortened by use of a period after *wilderness* instead of the comma used there in the original title, effectively making "with special reference to the geology and zoology of the Floridian Peninsula" a subtitle. The only other discernible difference between the 1886 and 1887 title pages is that the word *Explorations* is in slightly smaller type on the 1887 title page.

The final version of the *Explorations* also has a volume title page denoting the work as Volume 1 of the Transactions of the Wagner Free Institute of Science of Philadelphia, and bearing the date of May, 1887. Between this volume title page and the *Explorations* title page, there is an additional page listing the Trustees and Faculty of the Wagner Free Institute of Science. The copy of the final version in the library of the Division of Mollusks, National Museum of Natural History has, under the printed date of May, 1887 on the volume title page, the holograph notation "Rec'd. June 21st" in Dall's handwriting.

This copy, and the copy in the library of the senior author, has as the running title *Transactions of the Wagner Free* (verso) *Institute of Science* (recto). The running title is mentioned as there was a later printing, identical to the original except for the running title. The date of this later printing has not been established, but the junior author's copy was purchased directly from the Wagner Free Institute in 1938, and it is this later printing. In this printing the running title is *Explorations in Florida* (verso)

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*Research Associates. (Department of Invertebrate Zoology and Department of Paleobiology, respectively)

and an indication of the subject under discussion, *e.g., Little Sarasota Bay* (recto). The only other difference in this printing is that the title page listing the Trustees and Faculty is placed after the title page.

The *Explorations* was reprinted by the Paleontological Research Institution in 1964 as Volume IV, number 33, of *Paleontographica Americana.* This reprint has the running title of the original printing.

Heilprin's taxa have been reviewed in several faunal studies (Dall, 1890-1903, 1915; Mansfield, 1937; Olsson and Harbison, 1953; and others) and in various monographs of included genera. Without exception the date of 1887 has been cited for all taxa of the *Explorations*. One nomenclatural change, as a result of correct dating, is the reinstatement of *Mitra lineolata* Heilprin, 1886, previously thought to be preoccupied by *Mitra lineolata* Bellardi, 1887, and unnecessarily renamed *Mitra heilprini* Cossmann, 1899.

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July 31, 1986

REVIEW

QUATERNARY GEOLOGY AND ENVIRONMENT OF CHINA, by Liu Tungsheng. Publishedby China Ocean Press, Beijing, China, and distributed by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, x + 301 pp., illus., $69.50

Preparatory to the 11th INQUA Congress in August 1982, a symposium was held at Beijing in February 1982, summarizing the result of Quaternary research in China in recent years. The forty-two papers and eighteen abstracts presented here are from that symposium. These papers can be divided into six parts, Quaternary Stratigraphy (8 whole texts, 5 abstracts); Lithology and Genesis of Quaternary Deposits (10, 2); Quaternary Flora and Fauna (6, 3); Quaternary Paleogeography (13, 5); Prehistoric Man and his Material Culture (1, 1); and, Natural Resources of Quaternary Deposits (4, 2).

Much useful information is included, though the volume suffers from the unevenness characteristic of symposium compilations. However, it does present an overview of Quaternary research in China which is a valuable reference.

—H.C.S.

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TULANE UNIVERSITY OF LOUISIANA
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TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

Volume 19, Number 3 December 15, 1986

COMMUNITY REPLACEMENT IN ESTUARINE PLEISTOCENE DEPOSITS OF EASTERN NORTH CAROLINA

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I. ABSTRACT

Nearly all examples of succession described from studies of fossiliferous sequences are, in fact, instances of a wholly different synecologic process. This process is *community replacement*, the gradual to abrupt substitution of one benthic community for another during changes in environmental settings. Requiring time spans intermediate between those needed for succession and community evolution, replacement yields a fossil record that can be termed a *community replacement sequence*. Such subevolutionary sequences arise by 1) gradual replacement, mainly involving adjustments in species-abundance distributions with some minor species turnover, caused by slight alterations in habitats; and 2) attritional replacement, dominated by species turnover in habitats subjected to more rapid and drastic environmental change.

A sequence of fossil beds in the middle Pleistocene Flanner Beach Formation, Neuse River valley, North Carolina, represents a case of gradual community replacement. The community replacement sequence is reflected in the following vertical order of estuarine fossil associations within the Smith Gut and Beard Creek members: (1) open bay; (2) slightly restricted bay; (3) restricted lagoonal; (4) open lagoonal; and (5) lagoonal firm-ground. The proximal causes of replacement of the Flanner Beach communities were long-term changes in average salinity levels and intensity of seasonal environmental rigor, and, to a lesser extent, changes in substrate properties. These were ultimately related to a changing geomorphic configuration as barrier islands formed and isolated this segment of the western Atlantic coastline during an interglacial high-stand of sea level.

EDITORIAL COMMITTEE FOR THIS PAPER:
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II. INTRODUCTION

This paper surveys community temporal dynamics, emphasizing the importance and uniqueness of replacement in the temporal-ecologic hierarchy of community changes. These changes range from authentic ecologic succession to community evolution, and involve biologic interactions, purely environmentally driven changes, or both kinds of forcing mechanisms acting together (Miller, 1986). A case of gradual community replacement preserved as a sequence of estuarine fossil associations is documented from the middle Pleistocene Flanner Beach Formation in the Coastal Plain of eastern North Carolina (Figure 1), and an attempt is made to identify the kinds of long-period changes in environmental factors that influenced the Flanner Beach soft-bottom communities. Finally, a conceptual model of gradual replacement of benthic communities, based on the Flanner Beach case study, is described.

III. COMMUNITY TEMPORAL DYNAMICS – A PALEOBIOLOGIC PERSPECTIVE

Temporal change in composition and structure of communities has been a dominant theme of ecological research since the first scientifically cogent treatments of succession-like phenomena were published early in this century (*e.g.*, Cowles, 1901; Clements, 1916). However, paleontologists did not develop an interest in similar themes until the appearance of Lowenstam's (1950, 1957) classic papers on ecologic zonation and development of Silurian reefs.

Paleoecologists have often confused or misinterpreted one or more of three major aspects of community temporal dynamics: (1) the temporal scope of processes that yield preservable patterns in the fossil record; (2) whether dominant control was autogenic or allogenic; and (3) the number of different communities involved in resultant patterns. Ecologists also have shown con-

TABLE 1. Patterns and rough estimates of durations of the different types of temporal dynamics involving soft-bottom marine and estuarine communities.

Process	Pattern	Approximate Duration (Years)	Predominant Interaction Involved
COMMUNITY EVOLUTION	Origin and development of new community types, community structural divergence, community displacements and major faunal turnovers; yields *community lineages*	10^5–10^7	Species-Environment, Species-Species
COMMUNITY REPLACEMENT	Abrupt to gradual community transitions caused by environmental changes yielding *community sequences*	10–10^5 (?)	Population-Environment
PATCH DEVELOPMENT	Amalgamated seres and/or pseudoseres	10–10^3 (?)	Organism-Organism and/or Organism-Environment
COMMUNITY RESPONSE	Allogenic, seasonal or cyclic response to short-period environmental changes yielding *pseudoseres*	1–10 (?)	Organism-Environment
ECOLOGIC SUCCESSION *(sensu stricto)*	Autogenic, biotic changes in community structure yielding *seres*	1-10	Organism-Organism

fusion with regard to the last two of these properties (see discussion in McCall and Tevesz, 1983). Many recent paleoecologic studies describe changes within vertical sequences of fossils as some form of succession, operating through a wide range of time spans, and driven by both dynamic biologic processes within communities and by changes in environmental gradients or qualities. McCall and Tevesz (1983, p. 159), in discussing the concept of "allogenic succession," criticized the practice of mixing temporal hierarchies, invoking both autogenic and allogenic causative factors, and generally misapplying the concept of succession in stating: "It is against the weight of the more common usage of the term *succession*, it is confusing, and it is overbroad, emptying the idea of succession of any nontrivial meaning." They argued for restriction of the term succession to changes occurring in communities during short periods of time (usually less than ten years for soft-bottom communities) caused for the most part by internal, biotic interactions shaping composition and structure. More rigorous application of concepts in the recognition, description, and modeling of temporal dynamics would eliminate much of the existing confusion and facilitate better communication with ecologists.

To show the differences between patterns of change through time in benthic communities, major categories of temporal dynamics are briefly outlined, beginning with changes that are framed in the shortest durations (Miller, 1986). Table 1 is a summary of this hierarchy of community changes.

Ecologic Succession. Because of persistent interest in successional patterns and processes, a vast literature has accumulated on these subjects, mainly with regard to terrestrial plant communities (for good reviews see: Keever, 1950; Odum, 1969; Drury and Nisbet, 1973; Horn, 1974; Pickett, 1976; Connell and Slatyer, 1977). Definitions of ecologic succession usually contain three elements: (1) Succession is a change in the composition and structure of a community through time, following the invasion of an unoccupied habitat. (2) Changes in composition and structure result primarily from population interactions within the successional system. (3) Succession is "orderly" in the sense that patterns (seres) can be more or less recurrent in space and time, and because the life-history strategies of component populations and complexity of biotic interactions change regularly during successional sequences (McCall and Tevesz, 1983; Odum, 1969, Table 1). I exclude from this category of community change so-called "allogenic succession," encompassing short-period, environmentally-controlled temporal dynamics, as well as longer-period, subevolutionary transitions, such as community replacement as defined below.

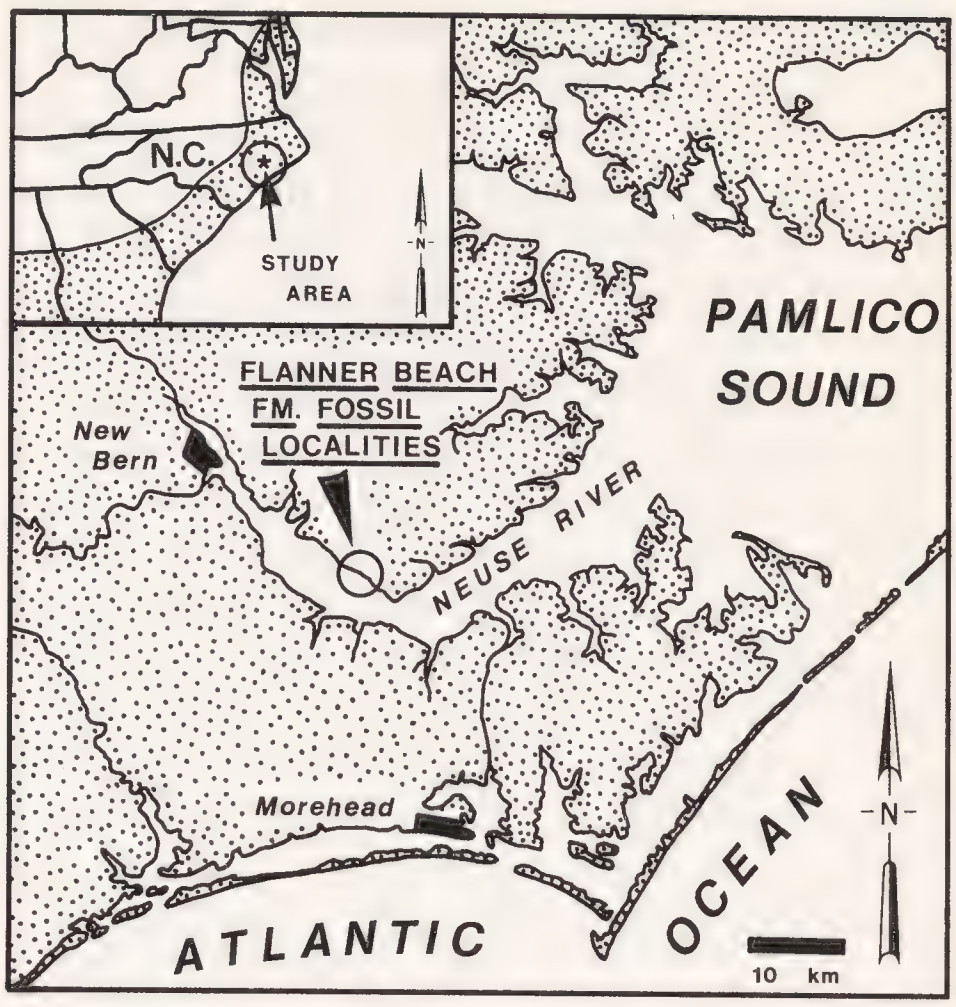

Figure 1. Location map showing fossil localities in the Flanner Beach Formation, eastern North Carolina. Stippled pattern represents extent of Atlantic Coastal Plain deposits.

Studies of modern estuarine soft-bottom succession that are relevant to interpretation of sequences of autochthonous fossil associations include: Boesch *et al.*, 1976; Levinton, 1977; McCall, 1977; Rhoads, Aller, and Goldhaber, 1977; Rhoads, McCall, and Yingst, 1978; Rhoads and Boyer, 1982; and McCall and Tevesz, 1983. These contributions point out three important properties of benthic community succession in modern environments: (1) successional sequences take place in timespans about as long as the lifespan of the most long-lived, slow-growing species, which are usually "equilibrium" or "phys-

iologically-resilient" species; (2) successional stages are characterized by organisms with differing population dynamics (*e.g.*, early stages are characterized by large populations of r-selected and opportunistic species; later stages include fewer opportunists, but have more K-selected and slow-growing species); and (3) episodes of succession take place when biotic interactions are more important, and alternate with periods when community dynamics are dominantly conformational and under the control of environmental parameters (*e.g.*, warm *vs.* cold seasons).

It is generally conceded that few convincing examples of ecologic succession have been documented from fossil deposits. Equivocal examples have been described by Walker and Alberstadt (1975), Walker and Parker (1976), and M. E. Johnson (1977). Significantly, Wilson (1985) reported recently what appears to be a plausible example of secondary ecologic succession involving cobble-encrusting organisms that inhabited an Upper Ordovician hardground, which suggests that examples may yet be found.

Community Response. Short-term changes in the composition and structure of communities resulting from allogenic environmental fluctuations, not leading to complete replacement of one community by another, are here termed *community response* (Table 1). Response probably alternates with ecologic succession in temperate estuarine and shallow marine settings, wherein seasonality is an important determinant of community structural changes (see Tenore, 1972; Boesch *et al.*, 1976). The resultant cyclic patterns produced by community response to gradually, sometimes seasonally, changing environmental rhythms or cues are here termed *pseudoseres*. Pseudoseres preserved as ecologically graded, microstratigraphic sequences of autochthonous fossils should be nearly impossible to differentiate from true successional sequences (seres), except where the effects of seasonality can be independently inferred from facies analysis and paleoclimatologic data. Sharp, aperiodic environmental change can have the impact of "downgrading" both successional and response sequences to earlier, less complex stages (*cf.* R. G. Johnson, 1972; Rollins *et al.*, 1979). Perhaps certain examples of short-term "allogenic succession" identified in the fossil record could be re-interpreted as preserved patterns of community response.

Patch Development. Little is known about the development, growth, and decline of benthic, soft-bottom patches (see Lorenz, 1973; Levin and Paine, 1974; Wilson, 1982). As defined here, patches are sites of prolonged occupation formed either by the amalgamation of seres resulting from ecologic succession, pseudoseres produced by community response cycles, or combinations of both (Table 1). Many thin shelly layers composed of autochthonous remains of ancient benthic communities probably represent patches of this type.

Community Replacement. Nearly all published descriptions of fossil succession are examples of community replacement (*e.g.*, Nicol, 1962; Donahue *et al.*, 1972; Goldring and Kaźmierczak, 1974; Bretsky and Bretsky, 1975; Walker and Alberstadt, 1975; Copper and Grawbarger, 1978; Toomey and Cys, 1979; Williams, 1980; Wolosz and Wallace, 1981). Many accounts of faunal transitions describe fossiliferous sequences compiled during long-term environmental changes affecting benthic community distributions in space and time, and thus represent additional examples of community replacement (Israelsky, 1949; Hudson, 1963; Kauffman, 1969; Stanton and Dodd, 1970; West, 1972; Alberstadt *et al.*, 1974; Donahue and Rollins, 1974; Shaver, 1974; Bromley, 1975; Lister, 1976; Bailey, 1977; Sundberg, 1980; Fürsich, 1981; Hickey and Younker, 1981; Isaacson and Curran, 1981; Beus, 1984). M. E. Johnson (1977) and Hoffman and Narkiewicz (1977) appear to have been the first workers to use the concept of replacement as it is applied in this paper. Rollins *et al.*, (1979) and Miller (1982) used the concept and terminology in a similar way for community transitions propelled by environmental changes.

The term "replacement" has been used as a label for other types of faunal transitions. One of the most common current uses of the term is in the form "ecologic replacement," which is sometimes used to

mean faunal element substitution in evolutionary time occurring when extinctions vacate niches in communities (Boucot, 1975; Raup and Stanley, 1978). This is really a kind of community evolution, as is the "community replacement" of Sepkoski and Sheehan (1983).

I restrict the term community replacement to *long-term* (involving at least hundreds of generations of average benthos), *subevolutionary community transitions caused by either abrupt or gradual changes in environmental contexts*. The preserved patterns of community replacement, analagous to seres and pseudoseres, are here termed *community replacement sequences*. From a review of the literature on faunal transitions, it appears that replacement is a poorly understood, yet widespread and fundamental dynamic property of biotic communities. It may be the most important ecologic explanation for changes in autochthonous fossil associations sampled through vertical stratigraphic sequences unbroken by unconformities (Miller, 1986).

Community Evolution. Community evolution is at the opposite end of the time spectrum from succession and response. Temporal dynamics leading to evolutionary transitions in benthic communities, involving faunal element substitution, appearance of new types of communities, community structural divergences, and biogeographic displacements of communities, probably occur in time spans of 10^5 to 10^7 years. Resultant patterns could be termed *community lineages* (Table 1). Discussions of this type of community change can be found in Olson (1952), Shotwell (1964), Bretsky (1969), Valentine (1973), Boucot (1975), and Watkins and Boucot (1975).

IV. FLANNER BEACH FORMATION – CASE HISTORY STUDY OF COMMUNITY REPLACEMENT

General Stratigraphy. DuBar and Solliday (1963) proposed the name Flanner Beach Formation for fossiliferous muddy sand and silt-clay beds of Pleistocene age exposed along the lower Neuse River, in east-central North Carolina (Figure 1). The formation was subdivided into three informal members by Mixon and Pilkey (1976), including: (1) the Arapahoe sand, comprising barrier island deposits cropping out along both sides of the Neuse River near the Suffolk Scarp in Pamlico and Craven Counties; (2) the Newport sand, consisting of similar barrier sands underlying ridge-and-swale topography just south of the Newport River in Carteret County; and (3) the correlative, fossiliferous, muddy sand and silt-clay backbarrier deposits of the Beard Creek member. I proposed (Miller, 1985a) that these informal members be promoted to formal lithostratigraphic units, and also described and named a fourth member composed of pebbly, fossiliferous muddy sand (Smith Gut Member), located at the base of the formation, that reflects early transgressive open-bay conditions.

The Smith Gut, Beard Creek, and Arapahoe Sand members are well-exposed in the vicinity of Beard Creek in southern Pamlico County (Figure 2). In this area, the Smith Gut and Beard Creek members are very fossiliferous in places and contain both thick, laterally extensive shell beds (major complex and major simple shell accumulations of Kidwell, 1982), and thin lenses, pods, and single-shell stringers (minor complex and minor simple shell accumulations of Kidwell, 1982). All of the shell beds consist largely of the valves of the small mactrid clam, *Mulinia lateralis* (Say).

Beds within the Smith Gut and Beard Creek members were deposited in a spatial-temporal mosaic of bay and lagoonal environments about 200,000 years B.P., during a world-wide high stand of sea level. The Flanner Beach Formation rests disconformably on an older Pleistocene unit, the James City Formation, and is bordered on the east by younger Pleistocene deposits informally known as the "Core Creek sand" (DuBar and Solliday, 1963; Mixon and Pilkey, 1976). If reported amino acid and uranium-series dates for the Flanner Beach are accurate (McCartan *et al.*, 1982; Cronin *et al.*, 1984), the unit is time-correlative with van Donk's (1976) Atlantic Basin oxygen-isotope stage 7.

Methods. Deposited during a single transgressive-regressive cycle of Pleistocene coastal inundation, lasting perhaps tens-of-thousands of years, the Smith Gut

and Beard Creek members were targeted for the study of long-period subevolutionary changes in deployment patterns of benthic communities. Rhythmic shelly layers in the Beard Creek area of Pamlico County were sampled at 20 to 40 cm vertical intervals (Figure 2). Fifteen, one-liter bulk samples of fresh sediment were washed on a sieve with 2 mm openings (measured diagonally). All identifiable fossil remains isolated in this way were identified, counted, and examined for signs of shell utilization by encrusting and boring organisms. Numbers of specimens were corrected to reflect the numbers of original individuals (*e.g.*, estimated number of bivalves of a particular species = number of articulated shells + [number of valves and valve fragments with beaks/2]), and these tallies were used to estimate relative abundances.

Taphonomy. Among the 75,748 identifiable specimens recovered from the samples, there are 143 species of animals, 111 of which are mollusks. Members of the Porifera, Cnidaria, Bryozoa, Annelida, Arthropoda, Echinodermata, and Chordata were also identified. An abundant and varied microbiota occurs in the Flanner Beach, but these organisms were not studied. Of all species identified, 41 appear to be exotic and derived from adjacent,

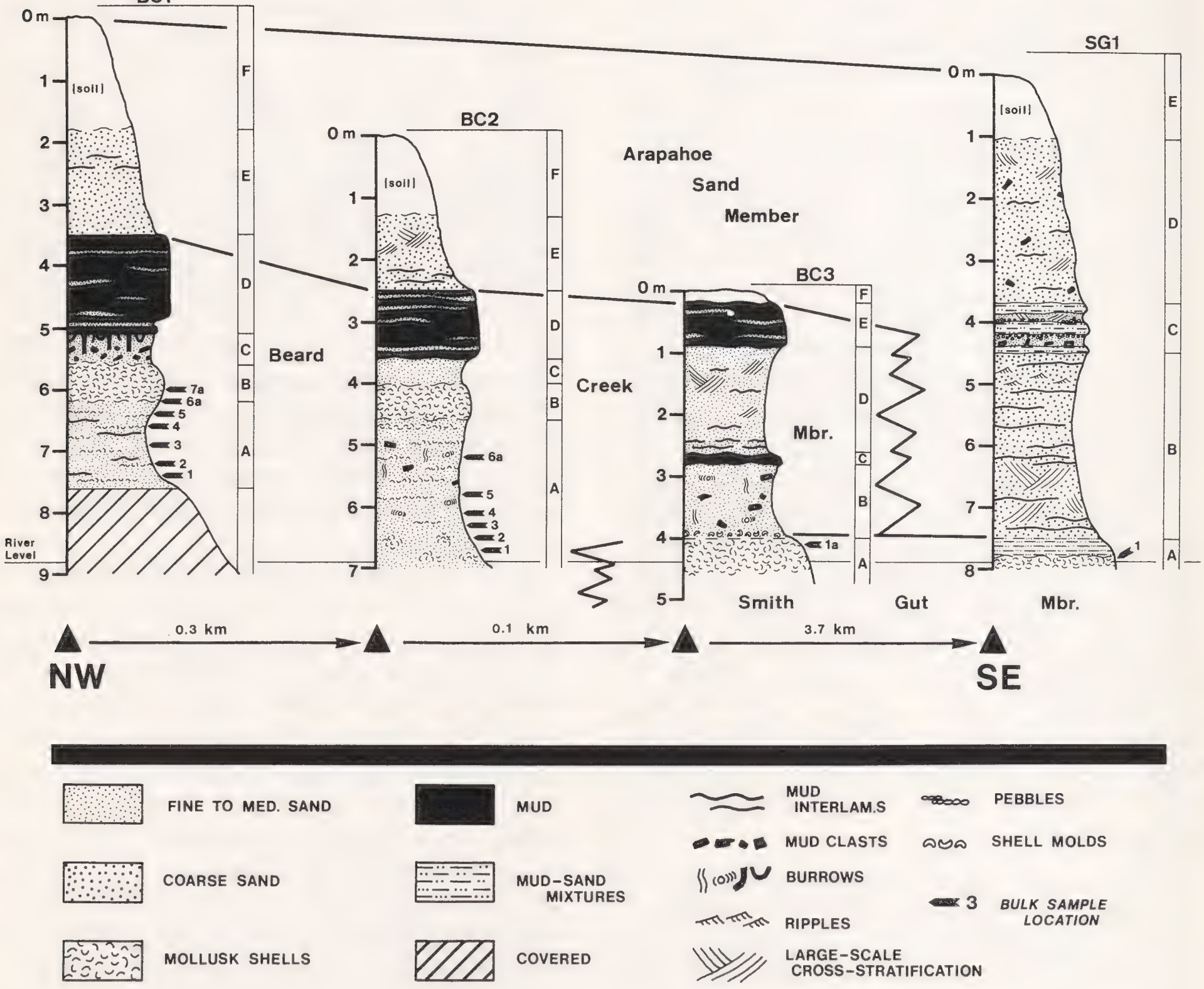

Figure 2. Stratigraphic panel diagram of bluff-line exposures of the Flanner Beach Formation in the vicinity of Beard Creek, southernmost Pamlico County, North Carolina. Exact locations of the measured sections are given in Appendix. Stratigraphic framework and depositional environments are discussed by Miller (1985a). Stratigraphic levels of bulk samples of fossils used in paleocologic analyses are indicated by arrows beside columns.

contemporary habitats, and 18 species were reworked from the subjacent James City Formation (Miller, 1984). All of the indigenous species are extant except one bivalve (Miller, 1985b). Complete inventories of fossils can be found in Miller (1984).

Explanations for the origin of shell beds in the Smith Gut and Beard Creek members must take into account the following characteristics: (1) all shelly accumulations, regardless of thickness, geometry, geographic extent, or stratigraphic elevation, are numerically dominated by *Mulinia lateralis*; (2) shell beds show evidence of varied scales of condensation and stratigraphic telescoping (see Kidwell, 1982); and (3) fossils are predominantly indigenous faunal elements, largely shiny and unabraded shells, in some places current-oriented and in others randomly oriented, and belong mainly to extant taxa that are known to inhabit mesohaline to polyhaline estuarine environments.

Mulinia lateralis is an opportunitic estuarine species capable of very rapid population growth owing to: (1) potential year-round gametogenesis (apparently controlled by ambient temperature); (2) very short generation times (about two months), typically with up to three generations/year; (3) rapid sexual maturation; and (4) a potential longevity of about two years (Calabrese, 1969; Levinton, 1970; Brande, 1979). Together with opportunistic soft-bodied metazoans, such as polychaete worms and amphipods, *M. lateralis* is among the first western Atlantic invertebrate species to reinvade modern benthic habitats that have been disturbed, destroyed, or ecologically "downgraded" (Rhoads, McCall, and Yingst, 1978).

In modern paralic environments along the American East Coast that are prone to aperiodic disturbances, such as those caused by increased sedimentation or the churning and resuspension of bottom sediments in storms, valves of *M. lateralis* are accumulating in large numbers (Biggs, 1967; Levinton, 1970). In samples from the Flanner Beach Formation, *M. lateralis* makes up 62 to 96% of individuals in fossil associations. Modern populations are especially sensitive to predation incurred as colonization of patches progresses, leading to large concentrations of dead shells (Virnstein, 1977). Most of the *M. lateralis* valves recovered from Flanner Beach samples, however, do not show *obvious* signs of predation (highest incidence is about 30%). Many of these incidences probably were not fatal and only involved nicks inflicted by crabs or fish along ventral edges of valves (see Bishop, 1975). It is unlikely that competition was a dominant factor shaping community structure in the shallow-water, estuarine benthic habitats of the Flanner Beach basin, in which the soft-bottom communities were highly, but not exclusively, physically controlled (see Sanders, 1968; R. G. Johnson, 1972). So it appears that allogenic, environmental processes might have caused the demise of localized *Mulinia* patches in this case.

Condensation and stratigraphic telescoping of fossiliferous beds can be caused by both biogenic and hydraulic/sedimentologic agencies, and by combinations of these kinds of processes (see Schäfer, 1972; Fürsich, 1978, 1982; Kidwell, 1982; Powell *et al.*, 1982; Kidwell and Jablonski, 1983, Table II). Thick shelly accumulations in the Smith Gut and Beard Creek members show signs of condensation resulting from low net sediment accumulation, but vary in terms of internal paleoecologic and biostratinomic complexity. These thick layers of shells have been intensively bioturbated, and microstratigraphic samples from them are likely to contain many generations of organisms and several seres/pseudoseres.

The primary concentrating process responsible for the thick shell beds in the Flanner Beach seems to have been low net sediment accumulation, as opposed to biogenic concentration, considering the environmental stratigraphic contexts: the thick shelly bed in the Smith Gut Member (Figure 2) was deposited during a rapid rise in sea level that quickly inundated a coastal lowland and subsequently created conditions of sediment starvation in a newly formed embayment, whereas the thick bed near the top of the Beard Creek Member (Figure 2) appears to be the result of sediment bypassing and/or winnowing in the environs of a tidal inlet in the nearby Arapahoe barrier (Miller, 1985a). In the course of accumulation, the beds were churned by the burrowing activities of infaunal organisms.

Deposition by transport and dumping or large-scale *in situ* winnowing during storms forming shelly lags does not seem likely because: (1) condition of most shells is unabraded (but almost all bivalves were disarticulated); (2) sediment size-grading and pronounced shell size-sorting were not observed, although these could result from bioturbation; (3) bottoms of beds do not show erosional or guttered surfaces; and (4) shell beds are never covered by plane-laminated or hummocky-laminated layers representing the waning phases of storms. The presence of a natural spectrum of growth stages among the more common species, and the low numbers of exotic and reworked shells compared to numbers of specimens belonging to indigenous estuarine taxa further argue against a storm origin for these thicker shell beds.

The thinner, tabular to lenticular shell beds and shelly pods within the Beard Creek Member (Figure 2) appear to be primarily the products of patch formation and other biogenic concentration processes, involving mixing of several superimposed seres/pseudoseres. Single-shell stringers seem to represent a single ecologic unit or event, but condensation and bioturbation have obliterated any internal ecologic grading that might originally have been present in the slightly thicker beds and lenses as a result of ecologic succession. Again, clear-cut evidence is lacking for storm influence in the formation of these thinner, more local accumulations of skeletons. It is likely that the backbarrier setting was somewhat protected from the effects of storm surges, but, alternatively, evidence of storm reworking and deposition may have been erased by biogenic alteration of sedimentary structures.

Surrounding the thinner shell beds in the Beard Creek Member are sparsely fossiliferous muddy sands containing only a few scattered shells. These intervals are either the least condensed and time-averaged fossil deposits in the Flanner Beach Formation, or represent intervals (areas of substrate) between periods (loci) of patch development. Both local stratigraphic expansion and temporary reduction of biotic input of skeletons may have been involved. The "barren" intervals might also represent bioturbated blankets of storm-deposited sediments.

In summary, the following factors most strongly influenced the origin and preservation of shelly concentrations in bay and backbarrier lagoonal facies of the Flanner Beach Formation: (1) telescoping/expansion of local stratigraphic sequences as a result of variable net sediment accumulation; (2) local increases in the production of skeletons owing to outbreaks of skeletalized, opportunistic clams and the subsequent recruitment of other shelled taxa during the development of patches; and (3) biogenic mixing of microstratigraphic levels and concentration of shells. Sedimentary condensation was the dominant factor in the formation of thick, major complex and major simple shell beds; whereas biogenic processes of concentration probably predominated in the formation of thin, minor complex and minor simple shell beds. Storm-related disturbance also could have been important, but strong evidence of this is lacking.

Paleosynecology. Preserved patterns of original community composition and structure are best represented among taxonomic groups that possess durable, mineralized skeletons, which translate into fossil remains with minimal information loss (Lawrence, 1968; Valentine, 1972; Schopf, 1978). Therefore, analysis of fossil associations focused mainly on gastropod and bivalve mollusks. Recognition of paleocommunity properties and patterns of change with time should have a relatively high degree of reliability in bay and lagoonal depositional sequences because: (1) fossils are derived from organisms that lived, died, and were buried essentially in place (Johnson, 1965; Warme, 1969; Warme *et al.*, 1976); (2) an appreciable fraction of original community components are mollusks, which have varied modes of feeding and substrate-niche preferences, and are easily fossilized; (3) short-term population variations, diversity oscillations, and seasonal effects are averaged into composite synecologic pictures of original community composition and structure during the gradual, *in situ* accumulation of shells (Walker and Bambach, 1971; Warme *et al.*, 1976; Peterson, 1977); and (4) net

sediment accumulation rates in backbarrier environments in general could potentially preserve patterns of community temporal dynamics such as replacement, and rarely succession and response, and the resultant sequences normally contain few extremely condensed intervals or major stratigraphic gaps (*cf.* shelly open-shelf sequences: Schindel, 1980).

The paleosynecologic analysis of Flanner Beach fossils uses compositional attributes of fossil associations (taxonomic composition, abundance, species richness, and dominance and diversity of mollusks), trophic and substrate-niche proportions, and general patterns of predation and overgrowths of skeletons. When preserved community patterns are traced through stratigraphic frameworks, it is possible to document the synecologic histories of depositional sequences (Miller, 1982), and inferences concerning the causes of community change through time can be tested.

Compositional attributes were assessed by the following standard methods: (1) compilation of species lists of indigenous faunal components; (2) estimation of absolute and relative abundance of individuals based on counts of skeletal remains, corrected to relate numbers of skeletal parts to original numbers of individuals in the living community; (3) ranking taxa using absolute abundances; (4) determination of overall species richness (total number of indigenous species) and molluscan species richness; and (5) calculation of molluscan dominance, diversity, and evenness indices. Molluscan dominance for each sample was computed by substitution in the equation:

$$C_m = \sum_{i=1}^{S_m} p_i ,$$

where S_m is species richness of mollusks and p is the proportion of individuals belonging to the ith molluscan species. Molluscan diversity was computed by substitution in the Shannon-Weaver equation:

$$H' = -\sum_{i=1}^{S_m} p_i \ln p_i ,$$

where ln is the natural logarithm. Molluscan evenness was calculated by substitution in the equation:

$$E_m = H_m / \ln S_m .$$

Use of all three equations for paleocommunity analysis is described in Dodd and Stanton (1981). Only mollusks are used in the computation of these indices in this study because original species richness and abundance in dead shell accumulations of mollusks derived from living communities should be reliably represented in fossil associations deposited in protected bay and lagoonal settings. Estimates of richness and abundance for other important groups of organisms (*e.g.*, cirripeds, bryozoans) can be only approximate owing to dismemberment of skeletons or fragmentation of colonies after death. Table 2 gives indices calculated for all samples. Table 3 lists the most abundant species and average compositional indices for fossil associations recognized in bulk samples from the Smith Gut and Beard Creek members.

Trophic proportions were estimated for each sample using all indigenous faunal components by employing the methods of paired substrate-niche and feeding behavior ternary diagrams, as described by Scott (1976, 1978). Because nearly all indigenous fossil components belong to extant species, generalized substrate and feeding categories could be determined using the literature on modern estuarine and marine organisms from the western Atlantic Ocean and Gulf of Mexico. Figure 3 shows the "descriptive trophic structure" (Scott, 1978) of fossil associations including the most abundant mollusk, *Mulinia lateralis*; Figure 4 shows trophic structure with *M. lateralis* excluded.

A series of comparative studies of living benthic communities and their associated

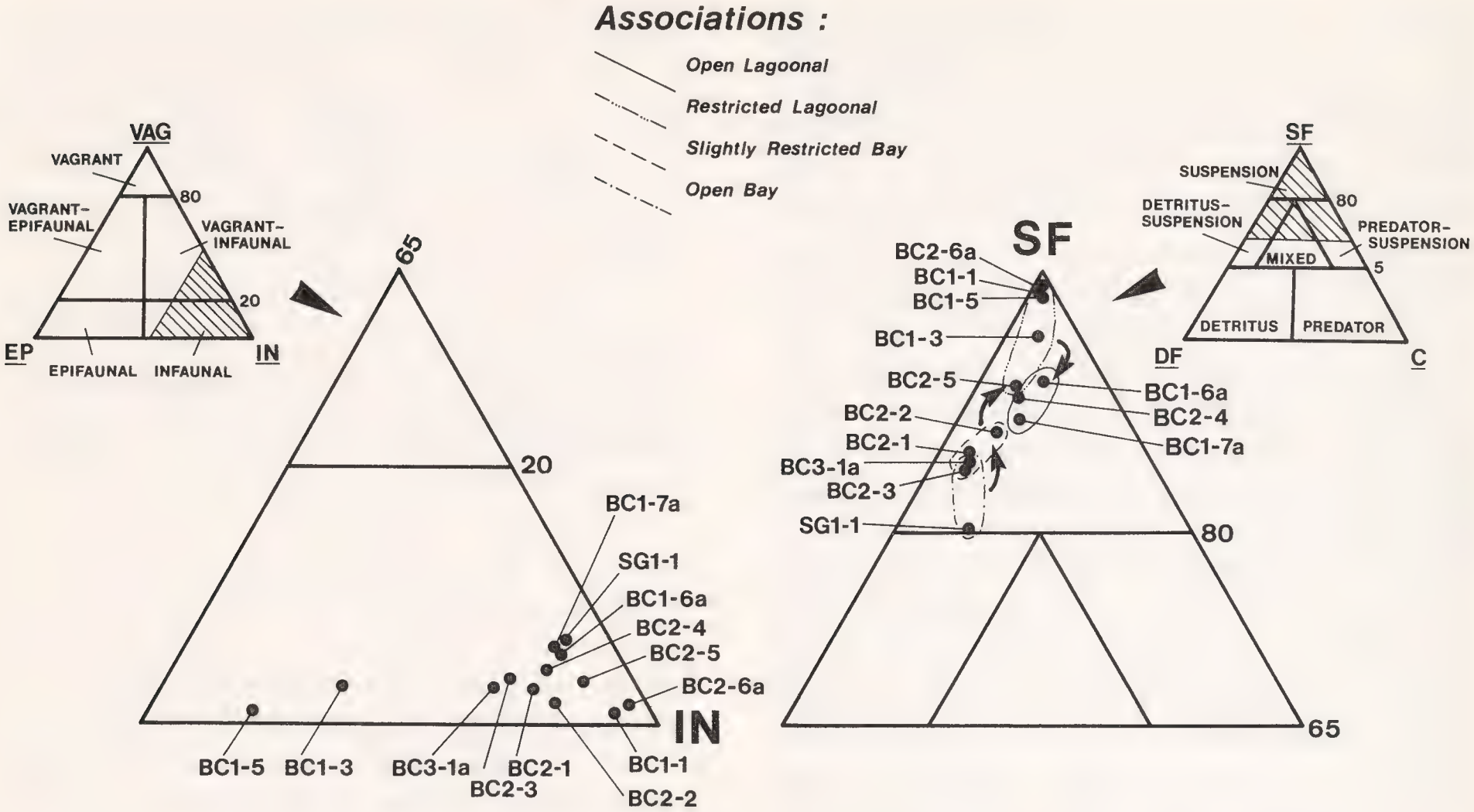

Figure 3. Descriptive trophic structure of Flanner Beach fossil associations. Sample numbers correspond to those used in Figure 2. Method of constructing paired ternary diagrams to represent preserved trophic proportions is described in Scott (1976, 1978). Symbols have the following meanings: *VAG*, vagrant; *EP*, epifaunal; *IN*, infaunal; *SF*, suspension-feeding; *DF*, detritus feeding and algal grazing; *C*, carnivorous and parasitic. Detailed views of the infaunal corner of substrate-niche and suspension-feeding corner of feeding behavior diagrams are shown.

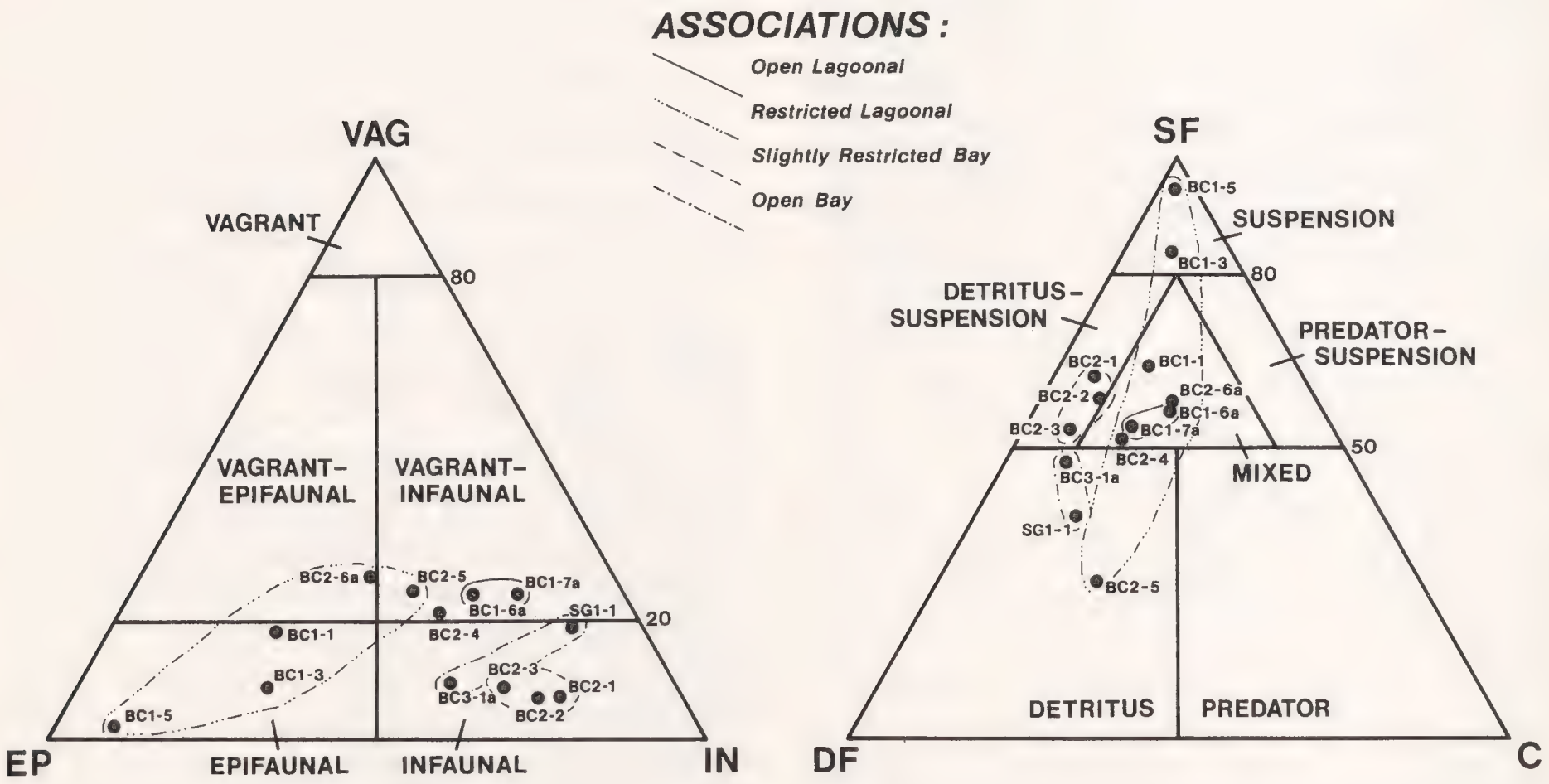

Figure 4. Descriptive trophic structure with *Mulinia lateralis* deleted. Sample numbers refer to Figure 2, and method of constructing diagrams and symbols used are same as in Figure 3.

TABLE 2. Quantitative compositional attributes of fossil associations from the Flanner Beach Formation. Symbols are defined at foot of table. Samples are listed in stratigraphic order (see Figure 2).

Sample	Fossil Association	S′	S	S_{ex}	S_{re}	S_m	C_m	H'_m	E_m
BC1-7a	Open lagoonal	60	59	2	0	49	0.85	1.07	0.27
BC1-6a	Open lagoonal	55	48	7	0	38	0.69	0.87	0.24
BC1-5	Restricted lagoonal	27	22	5	0	19	0.90	0.31	0.11
BC1-4*	Restricted lagoonal	7	6	1	0	5	0.73	0.61	0.38
BC1-3	Open lagoonal	51	43	7	0	35	0.72	0.78	0.22
BC2-6a	Restricted lagoonal	31	22	9	0	19	0.95	0.17	0.06
BC1-2*	Restricted lagoonal	18	16	2	0	15	0.37	1.56	0.58
BC1-1	Restricted lagoonal	20	17	2	0	16	0.96	0.13	0.05
BC2-5	Restricted lagoonal	23	19	3	0	18	0.81	0.57	0.20
BC2-4	Transitional (between slightly restricted bay and restricted lagoonal)	31	28	3	0	25	0.74	0.80	0.25
BC2-3	Slightly restricted bay	43	39	1	2	32	0.56	1.23	0.35
BC2-2	Slightly restricted bay	68	56	8	7	41	0.58	1.15	0.31
BC3-1a	Open bay	87	56	18	15	42	0.63	1.04	0.28
BC2-1	Slightly restricted bay	56	49	2	6	35	0.47	1.31	0.37
SG1-1	Open bay	107	54	38	20	44	0.49	1.49	0.39

Symbols used in column headings:

S′ – uncorrected, raw species richness of fossil deposit; because in a few instances species could not be related to original habitats or stratigraphic levels, S′ is not always exactly equal to S + S_{ex} + S_{re} (see below)
S – corrected species richness of the indigenous fossil association; environmentally exotic and reworked species eliminated
S_{ex} – richness of contemporary, environmentally exotic species
S_{re} – richness of reworked species from the subjacent James City Formation
S_m – richness of indigenous molluscan species; used in calculations of C_m, H'_m, and E_m (see text)
C_m – molluscan species dominance
H'_m – molluscan species diversity
E_m – molluscan species eveness
* – sample from an expanded interval between shelly accumulations; not time-averaged to the same degree as other shelly layers

dead shell accumulations in modern environments has shown that preserved trophic proportions are usually poor representations of original trophic structure, and that reconstruction of original trophic dynamics of holistic communities based on these patterns is generally not possible (Stanton, 1976; Stanton and Dodd, 1976). Trophic structure studies still hold promise in paleoenvironmental analyses that utilize fossil associations from protected depositional settings, and in documentation of the complexity of species interactions in sequences of ancient communities (see Scott, 1978; Stanton and Nelson, 1980). Descriptive trophic structure thus has value in yielding additional paleosynecologic descriptors useful in tracing fossil associations through bay and lagoonal deposits in the Smith Gut and Beard Creek members.

Predation and overgrowth analysis of four samples, representing each of the fossil associations, was undertaken to document changes in patterns and complexity of biotic interactions and dead-shell utilization through time. Results are presented in Table 4. Like descriptive trophic structure, changes in the patterns of predation and skeletal overgrowths between fossil associations in vertical stratigraphic sequences are used to trace changes in paleocommunities through time.

TABLE 3. Most common taxonomic components of fossil associations in the Smith Gut and Beard Creek members. Only taxa comprising ≥0.5% of individuals within at least one sample are listed, and all symbols are defined at bottom of table. Complete faunal inventories for each sample, including rare species, are listed in Miller (1984, Appendix III).

Species	Type of Organism	Rank*	Average Absolute Abundance	Average Relative Abundance	Substrate-Niche/Feeding Category
I. *OPEN BAY ASSOCIATION* (2 SAMPLES)					
Mulinia lateralis	Bi	1	1685.5	72.4%	IN/SF
Nuculana acuta	Bi	2	161.5	6.9	IN/DF
Balanus spp.	Ci	3	110.0	4.7	EP/SF
Tellina texana	Bi	4	82.5	3.5	IN/DF
Acteocina canaliculata	Ga	5	50.0	2.1	VAG/C
Ensis directus	Bi	6	34.5	1.5	IN/SF
Corbula contracta	Bi	7	30.0	1.3	IN/SF
Solen viridis	Bi	8	22.0	0.9	IN/SF
Nucula proxima	Bi	8	22.0	0.9	IN/DF
Yoldia limatula	Bi	9	19.5	0.8	IN/DF
Pandora trilineata	Bi	10	15.5	0.7	IN/SF
Mysella planulata	Bi	11	14.0	0.6	EP/SF
Abra aequalis	Bi	12	13.5	0.6	IN/DF
Holoporella spp. (3?)	Br	13	12.0	0.5	EP/SF
Anadara transversa	Bi	14	10.5	0.5	IN/SF
Nassarius trivittatus	Ga	15	9.5	0.4	VAG/DF
Electra spp. (2?)	Br	16	8.5	0.4	EP/SF
Macoma tenta	Bi	17	7.0	0.3	IN/DF
Diplodonta notata	Bi	17	7.0	0.3	IN/SF
Erycina floridana	Bi	18	6.5	0.3	IN?/SF?
Crepidula sp.	Ga	19	6.0	0.3	EP/SF
$\bar{S} = 55$	$\bar{S}_m = 43$		$\bar{C}_m = 0.56$	$\bar{H}'_m = 1.26$	
II. *SLIGHTLY RESTRICTED BAY ASSOCIATION* (3 SAMPLES)					
Mulinia lateralis	Bi	1	1582.7	70.4%	IN/SF
Ensis directus	Bi	2	226.0	10.1	IN/SF
Balanus sp.	Ci	3	96.0	4.3	EP/SF
Tellina texana	Bi	4	79.3	3.5	IN/DF
Nuculana acuta	Bi	5	58.0	2.6	IN/DF
Nucula proxima	Bi	6	41.7	1.9	IN/DF
Abra aequalis	Bi	7	32.0	1.4	IN/DF
Yoldia limatula	Bi	8	21.3	0.9	IN/DF
Solen viridis	Bi	9	20.3	0.9	IN/SF
Acteocina canaliculata	Ga	10	17.3	0.8	VAG/C
Corbula contracta	Bi	11	14.0	0.6	IN/SF
Busycon sp.	Ga	12	13.7	0.6	VAG/C
Membranipora spp. (2?)	Br	13	10.7	0.5	EP/SF
Holoporella spp. (2?)	Br	13	10.7	0.5	EP/SF
Mysella planulata	Bi	14	9.7	0.4	EP/SF
Anadara transversa	Bi	15	6.0	0.3	IN/SF
Mitrella lunata	Bi	16	5.3	0.2	VAG/C?
Busycon sp. cf. *B. carica*	Ga	17	4.0	0.2	VAG/C
$\bar{S} = 48$	$\bar{S}_m = 36$		$\bar{C}_m = 0.54$	$\bar{H}'_m = 1.23$	

(Continued next page)

III. *TRANSITIONAL ASSOCIATION* (1 SAMPLE)

Mulinia lateralis	Bi	1	861	80.7	IN/SF
Balanus sp.	Ci	2	54	5.1	EP/SF
Tellina texana	Bi	3	39	3.7	IN/DF
Ensis directus	Bi	4	18	1.7	IN/SF
Acteocina canaliculata	Ga	4	18	1.7	VAG/C
Nuculana acuta	Bi	5	10	0.9	IN/DF
Corbula contracta	Bi	5	10	0.9	IN/SF
Solen viridis	Bi	6	9	0.8	IN/SF
Nucula proxima	Bi	7	7	0.7	IN/DF
Mysella planulata	Bi	7	7	0.7	EP/SF
Terebra dislocata	Ga	8	6	0.6	VAG/C
Abra aequalis	Bi	9	5	0.5	IN/DF

$S = 28$ $S_m = 25$ $C_m = 0.74$ $H'_m = 0.80$

IV. *RESTRICTED LAGOONAL ASSOCIATION* (4 SAMPLES)

Mulinia lateralis	Bi	1	1592.3	89.4%	IN/SF
Balanus sp.	Ci	2	145.0	8.1	EP/SF
Acteocina canaliculata	Ga	3	10.3	0.6	VAG/C
Tellina texana	Bi	4	9.0	0.5	IN/DF
Ensis directus	Bi	5	8.5	0.5	IN/SF
Nassarius trivittatus	Ga	6	6.8	0.4	VAG/DF
Nucula proxima	Bi	7	3.5	0.2	IN/DF
Nuculana acuta	Bi	8	3.3	0.2	IN/DF
Abra aequalis	Bi	9	2.3	0.1	IN/DF

$\bar{S} = 20$ $\bar{S}_m = 18$ $\bar{C}_m = 0.91$ $\bar{H}'_m = 0.30$

V. *OPEN LAGOONAL ASSOCIATION* (3 SAMPLES)

Mulinia lateralis	Bi	1	4436.3	78.0%	IN/SF
Balanus sp.	Ci	2	321.3	5.7	EP/SF
Ensis directus	Bi	3	320.0	5.6	IN/SF
Tellina texana	Bi	4	162.0	2.8	IN/DF
Acteocina canaliculata	Ga	5	124.0	2.2	VAG/C
Corbula contracta	Bi	6	58.7	1.0	IN/SF
Nassarius trivittatus	Ga	7	54.0	0.9	VAG/DF
Mysella planulata	Bi	8	44.7	0.8	EP/SF
Solen viridis	Bi	9	36.3	0.6	IN/SF
Nucula proxima	Bi	10	29.3	0.5	IN/DF
Nuculana acuta	Bi	11	29.0	0.5	IN/DF
Membranipora sp.	Br	12	25.0	0.4	EP/SF
Terebra dislocata	Ga	13	24.0	0.4	VAG/C
Abra aequalis	Bi	14	21.3	0.4	IN/DF

$\bar{S} = 50$ $\bar{S}_m = 40.7$ $\bar{C}_m = 0.75$ $\bar{H}'_m = 0.91$

EXPLANATION OF SYMBOLS:

* – Based on average absolute abundance

Types of organisms:
Bi – bivalve mollusk
Ga – gastropod
Ci – cirriped crustacean
Br – bryozoan

Generalized substrate-niche designations:
IN – infaunal, for the most part sedentary or ranging over short distances
EP – epifaunal, for the most part sedentary or attached
VAG– vagrant, capable of frequent or prolonged movements

(Continued next page)

Generalized feeding behavior designations:
SF – suspension feeder
DF – detritus feeder, including herbivores and microphagous scavengers
C – carnivorous, including parasites and macrophagous scavengers

Compositional indices (see text):
$\bar{S}$ – average overall species richness
$\bar{S}_m$ – average richness of molluscan species
$\bar{C}_m$ – average dominance of molluscan species
$\bar{H}'_m$ – average species diversity of mollusks

Fossil Associations. As used here, a fossil association is the *preserved remains of a single, once-living biotic community*. Five associations were recognized in bulk samples. These included, in ascending stratigraphic order: (1) open bay association; (2) slightly restricted bay association; (3) a transitional association (between slightly restricted bay and restricted lagoonal); (4) restricted lagoonal association; and (5) open lagoonal association. These associations were identified based on taxonomic composition, species-abundance distributions, preserved trophic structure, preserved patterns of species interactions, and relationships to original substrates. The five slightly different associations so recognized appear to be derived from a continuum of at least three estuarine benthic communities arrayed along environmental gradients in average salinity, degree of overall environmental rigor (disturbance, seasonality), and substrate properties. End-members in this model continuum were: (1) a muddy-sand-bottom, polyhaline, open bay community; (2) a sand-bottom, mesohaline, restricted lagoonal community; and (3) a shelly-bottom, polyhaline, open lagoonal community. Flanner Beach fossil associations are discussed briefly below.

Overall species richness, molluscan species richness, and molluscan diversity were highest in open bay associations from the Smith Gut Member (Table 3, Figure 5). As in all associations from the Flanner Beach, *Mulinia lateralis*, a shallow-infaunal suspension-feeder, was by far the numerically dominant component. Unlike other associations, however, the infaunal detritus-feeder *Nuculana acuta* ranked second, with balanid barnacles (possibly commensal with *M. lateralis*; see Brande, 1982), *Tellina texana* (another detritus-feeding, infaunal clam), and *Acteocina canaliculata* (a diminutive, probably carnivorous, opisthobranch snail) ranking third through fifth, respectively. Minor components included a variety of predatory snails, many kinds of clams, and a rare ahermatypic coral (*Astrangia* sp.). Species richness among bryozoans was relatively high with up to eight species. Using the descriptive trophic classification of Scott (1976), open bay associations can be classified as infaunal-suspension feeding; if *M. lateralis* is deleted, an infaunal-detritus feeding classification results (Figures 3, 4). Predation traces and epizoan overgrowths were varied and numerous (Table 4), suggesting patterns of species interaction and dead-shell utilization that were the most complex of any fossil associations from the Flanner Beach. Of all the associations sampled, open bay associations reflect conditions of average salinity and environmental stability closest to those of open shelf settings.

Stratigraphic levels just above the Smith Gut Member contained slightly restricted bay associations (Table 3; Figure 5), characterized by slightly lower overall species richness, molluscan species richness, and molluscan diversity. *Mulinia lateralis* was again the numerically dominant organism, but *N. acuta* receded to fifth in rank. The clam *Ensis directus*, a deep-burrowing suspension feeder as an adult, was second in abundance, followed by another suspension feeder, *Balanus* sp.; *Tellina texana* ranked fourth and *A. canaliculata* dropped to tenth. When *M. lateralis* is included in the trophic classification, associations are infaunal-suspension feeding; without the opportunistic mactrid, an infaunal detritus-suspension feeding trophic structure is indicated (Figures 3, 4). Variety and abundance of predation marks and epizoan overgrowths are diminished compared to open bay associations (Table 4)

TABLE 4. Patterns of predation, skeletal overgrowth, and dead-shell utilization in fossil associations from the Smith Gut and Beard Creek members. Patterns in the highest ranked host species are given for representative samples of each type of association. Sources used to identify predation traces and epizoans/endozoans included: Canu and Bassler, 1923; Boekschoten, 1966, 1967; Miller and Brown, 1979; Boucot, 1981. Symbols are defined at bottom of table.

TYPE OF PREDATION SIGN OR EPILITHIC/ ENDOLITHIC ORGANISM / HOST (with rank)	biogenic shell breakage, unrepaired (decapod crustaceans)	biogenic shell breakage, repaired	snail drillholes (naticid mesogastropods)	*Electra* pits (cheilostome bryozoan)	"*Spathipora*" borings (ctenostome bryozoan)	*Polydora* borings (polychaete annelid)	*Cliona* borings (demosponge)	*Holoporella* encrustations (cheilostome bryozoan)	*Smittina* encrustations** (cheilostome bryozoan)	balanid bases (cirriped crustacean)	balanid attachment scars
I. OPEN BAY ASSOCIATION (SAMPLE SG1-1, FIGURE 2)											
Mulinia lateralis (1)	A*	R	C	R^{i}	R	R	R	R	R^{i}	–	R
Nuculana acuta (2)	C	R	R	–	–	–	R*	–	–	–	–
Tellina texana (3)	C*	R	R	R	R	–	R*	–	–	–	–
Acteocina canaliculata (4)	C	C	C	–	R	–	–	–	–	–	–
Ensis directus (5)	A*	–	–	–	–	–	–	–	–	–	–
II. SLIGHTLY RESTRICTED BAY ASSOCIATION (SAMPLE BC2-2, FIGURE 2)											
Mulinia lateralis (1)	A	R	R	R^{i}	R	R	–	–	–	R	C
Ensis directus (2)	A*	R	–	R^{i}	–	–	–	–	–	–	–
Tellina texana (3)	A*	R	R	–	–	–	–	–	–	–	–
Balanus sp. (4)	C*	–	R	R	–	–	–	–	–	–	–
Nucula proxima (5)	C*	R	R	–	–	–	–	–	–	–	–
III. RESTRICTED LAGOONAL ASSOCIATION (SAMPLE BC1-1, FIGURE 2)											
Mulinia lateralis (1)	A	R	C	–	–	–	–	–	–	R	R
Balanus sp. (2)	–	–	–	–	–	–	–	–	–	–	–
Tellina texana (3)	C*	–	R	–	–	–	–	–	–	–	–
Acteocina canaliculata (4)	R	R*	–	–	–	–	–	–	–	–	–
Nuculana acuta (4)	R	–	R	–	–	–	–	–	–	–	–
Nassarius trivittatus (4)	A	C	C*	–	–	–	–	–	–	–	–
Ensis directus (5)	C*	–	–	–	–	–	–	–	–	–	–
IV. OPEN LAGOONAL ASSOCIATION (SAMPLE BC1-7a, FIGURE 2)											
Mulinia lateralis (1)	A	C	R	R^{i}	–	R	–	–	–	–	C
Ensis directus (2)	A*	R	–	R^{i}	–	–	–	–	–	–	–
Tellina texana (3)	A*	R	C	R	–	–	–	–	–	–	–
Balanus spp. (4)	C*	–	R	–	–	–	–	–	–	–	–
Acteocina canaliculata (5)	C	C	R	–	–	–	–	–	–	–	–

Explanation of Symbols:

A – abundant, > 25% of host shells show predation marks or epilithic/endolithic infestations
C – common, 5 to 25% of host shells
R – rare, < 5% of host shells
* – some examples may be due to non-biogenic damage to shell caused by post-entombment compressional breakage or chemical dissolution of shells
** – possibly an environmentally exotic or reworked faunal element
i – interior as well as exterior surfaces of host shells bored/infested
– – not observed

and bryozoan species richness declines. Slightly reduced or more frequently fluctuating ambient salinities appear to have controlled benthic community structure during accumulation of the slightly restricted bay association. This is supported by limited oxygen-isotope profiling of the Beard Creek Member using *M. lateralis* valves (Figure 6).

One sample contained a transitional fossil association that shared attributes of both the slightly restricted bay and restricted lagoonal associations (Table 3). Compositional indices had values intermediate between those of associations preserved at slightly higher and lower stratigraphic levels within the Beard Creek Member. As always, *M. lateralis* was by far the dominant component, with *Balanus* sp., *T. texana, E. directus*, and *A. canaliculata* following in rank order. Bryozoans were not found. With *M. lateralis* included, the transitional association can be classified as infaunal-suspension feeding; with the dominant clam excluded, the association is vagrant-infaunal mixed feeding (Figures 3, 4). This association of fossils reflects a gradual transition in all preserved structural attributes from conditions of higher salinity, probably polyhaline environments, to lower salinity, mesohaline environments. Its properties are significant because they reflect community reorganization "in progress" within a gradually changing backbarrier setting.

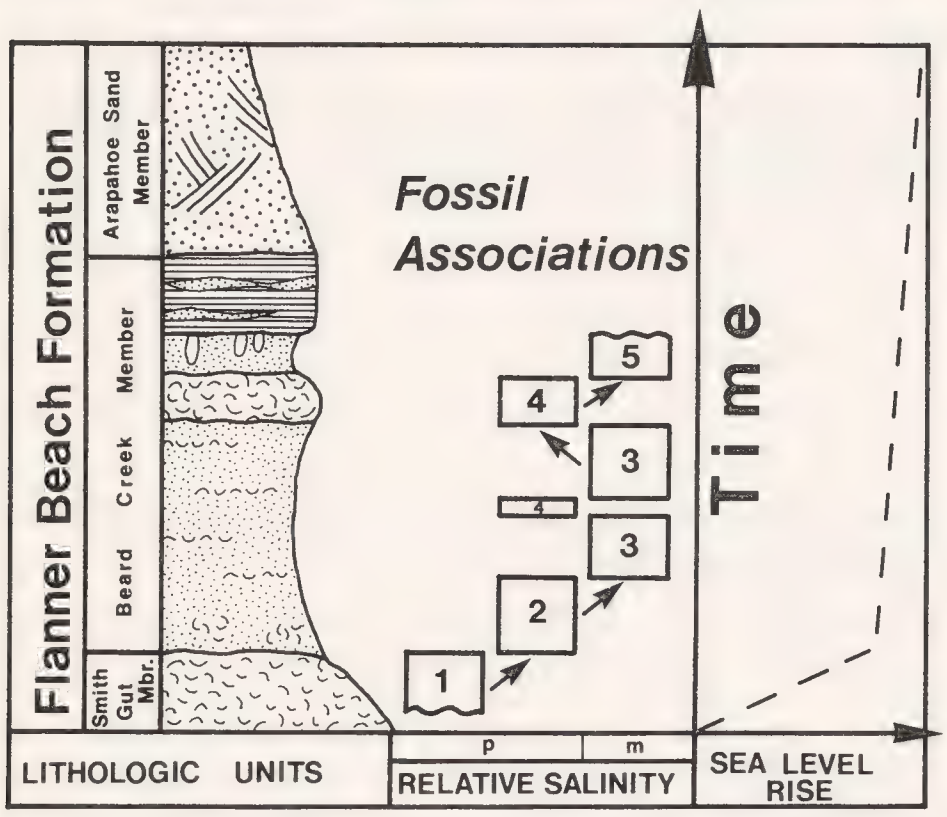

Figure 5. Community replacement sequence in the Flanner Beach Formation. Stratigraphic column is idealized, and sea level curve is shown as a dashed line. Symbols have the following meanings: (1) open bay fossil association; (2) slightly restricted bay association; (3) restricted lagoonal association; (4) open lagoonal association; (5) lagoonal firm-ground association; (p) polyhaline; (m) mesohaline. (Stratigraphic column not to scale.)

Lowest values of overall species richness, molluscan species richness, and molluscan diversity are found in the restricted lagoonal association. Molluscan dominance reaches its highest levels (Table 3; Figure 5) because samples contain the valves of *M. lateralis* and very little else. *Balanus* sp. ranked second, and *A. canaliculata, T. texana*, and *E. directus* were third through fifth. *Nuculana acuta* fell to eighth in rank. The only bryozoan recovered from samples was *Membranipora* sp. With *M. lateralis* included, descriptive trophic structure is again infaunal-suspension feeding; without *M. lateralis* the classification of Scott (1976) cannot be easily applied because points do not cluster in any of the field divisions on ternary diagrams (Figures 3, 4). The simplest patterns of predation and skeletal overgrowths were observed in this association, although *number* of obvious predation traces appeared to be as high as in the open bay association (Table 4). Preserved structural attributes indicate accommodation to the most rigorous environment of all fossil associations studied from the Flanner Beach Formation, and probabaly to the lowest levels of average salinity (as indicated in oxygen-isotope profile, Figure 6). Also, entombing sediments become much less muddy compared to lower stratigraphic levels.

Near the top of the Beard Creek Member is a thick shell bed containing an open lagoonal association, indicative of a return to higher levels of average salinity and greater community complexity. One thin shell bed near the middle of the Beard Creek Member also contained this association (see Figure 5). Overall species richness and molluscan species richness return to levels comparable to values from the open bay association. Molluscan dominance and diversity are similar to values for the transitional association (Table 3). Samples contained three bryozoan

species, on average. Although examples of predation traces and epizoan encrustations are numerous, earlier levels of complexity of species interactions and dead-shell utilization are not re-attained (Table 4). Abundance of *M. lateralis* causes the high molluscan dominance values. As in the transitional restricted lagoonal associations, balanid barnacles rank second, and *E. directus*, *T. texana*, and *A. canaliculta* follow in rank abundance. Numerically minor components include several species of carnivorous snails, many clams, and a rare coral (*Astrangia* sp.). With *M. lateralis* included, this association can be described as infaunal-suspension feeding; if the dominant clam is deleted, it is epifaunal to vagrant-infaunal, mixed to suspension-feeding (Figures 3, 4). The open lagoonal assocation reflects periodic re-establishment of more open circulation and higher, probably polyhaline salinities (supported by results of $^{18}O/^{16}O$ profiling, Figure 6), resulting from opening and migration of tidal inlets in the nearby Arapahoe barrier to the east. Substrates in this area were shelly sands, considering the abundance of fossil shells in samples.

Other fossil associations in the Flanner Beach Formation include a poorly preserved, lagoonal firm-ground association with *Cyrtopleura* sp., stratigraphically above the open lagoonal association (Figure 5). Beds containing this association are deeply weathered and were not used in the paleoecologic analysis. Notes on other fossil associations in the Flanner Beach are given in Miller (1984).

Gradual Community Replacement Sequence. Probably as a response to changes in circulation patterns and salinity levels controlled by the development and modification of nearby barrier islands, but also as a result of related local changes in substrate characteristics, paleocommunities of the Flanner Beach Formation changed through time. This is shown by the gradual transition of fossil associations preserved in the Smith Gut and Beard Creek members (Figure 5). The sequence of associations: (1) incorporates the greater part of an interglacial transgressive depositional sequence, which represents an estimated 2 x 10^4 years of environmental history (Miller, 1984); (2) does not include faunal shifts that correspond to sharp changes in sediment textures and assemblages of sedimentary structures; and (3) does not result from stratigraphic gaps in the section. Stratigraphic, isotopic, and paleontologic evidence point to gradual alteration in the environment of deposition (and organism habitats) through time as the cause of faunal transitions within the bay and backbarrier facies. As such, the sequence of associations is an example of gradual community replacement, and not ecologic succession or other succession-like phenomena.

The open bay association, from the lowest stratigraphic levels in the bluffs along the north side of the Neuse River, is the most species-rich and diverse of all the fossil associations studied. It was derived from a diverse, relatively complex, estuarine seafloor community that inhabited muddy, shelly sand substrates in waters of

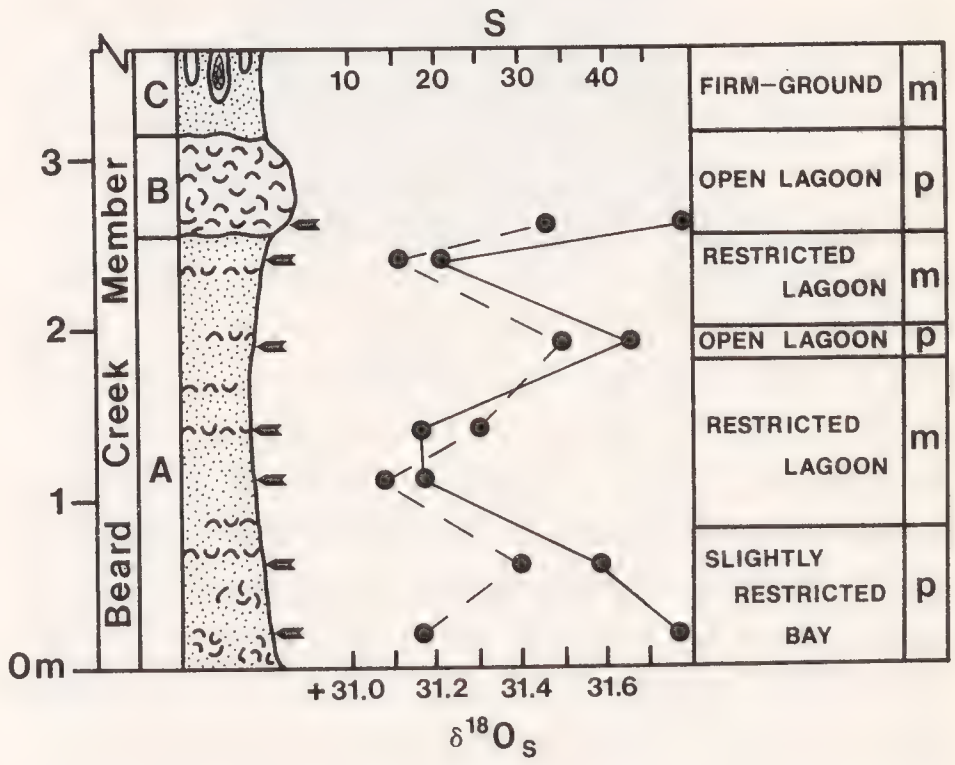

Figure 6. Diagram showing oxygen-isotope deviations ($\delta^{18}O_s$), relative to the SMOW standard (dashed line), and overall species richness (S) of fossil associations (solid line) plotted against stratigraphic elevation in a composite of columns BC1 and BC2 (Figure 2), beginning at base of the Beard Creek Member. Note that high values in $\delta^{18}O_s$ using *Mulinia lateralis* valves are usually matched by species-richness increases. Considering environment of deposition and paleoecologic properties, this pattern is probably indicative of cyclic changes in average salinity levels. Column at right lists fossil associations identified in bulk samples; *p*, polyhaline environment, *m*, mesohaline environment.

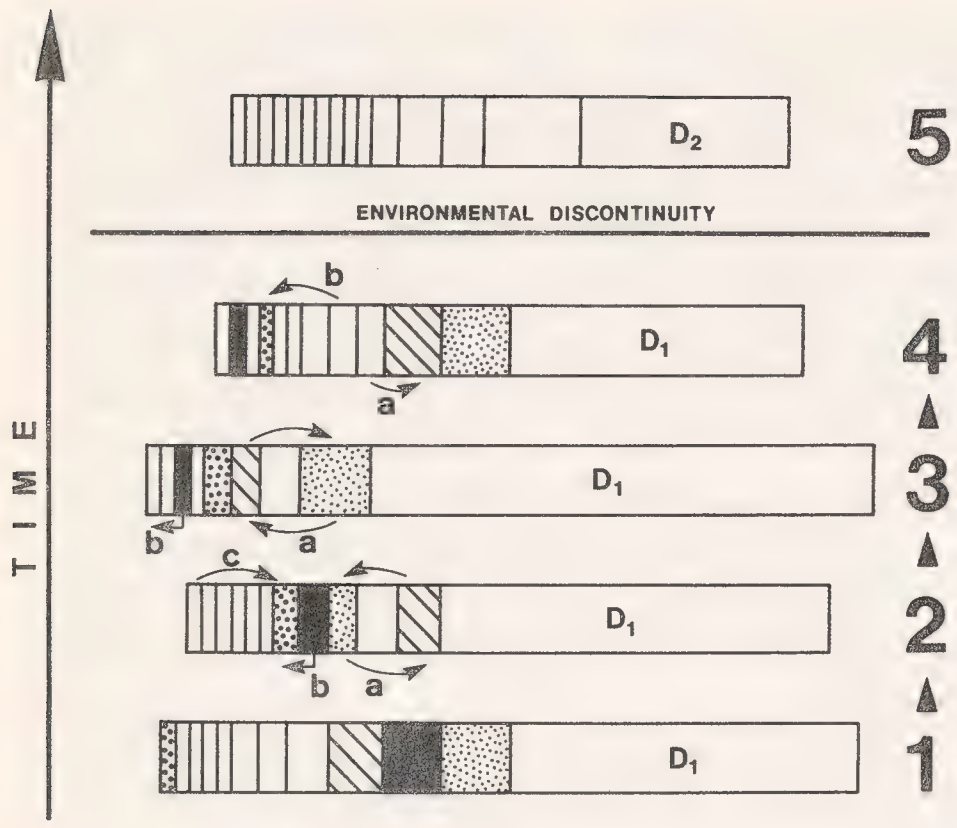

Figure 7. Conceptual model of gradual community replacement. Each numbered bar represents a community and the bar segments represent species abundances. As environmental qualities gradually change, one community gradually replaces another in a particular area. Stages in the sequence include: (1) initial appearance of a high-dominance community in a newly opened environment, with D_1 standing for a numerically dominant species and patterned bar segments indicating other less numerous faunal components; (2) the first community is then replaced by a similar community with slightly different structural properties, in which subdominant taxa have exchanged rank-abundance positions (a), certain taxa begin long-term demotion tends in abundance (b), and some lower rank taxa undergo jumps in abundance (c); (3) the second community is next reorganized to form a third community in which subdominant taxa re-exchange rank positions (a), demotion trends for some species continue (b), and some species completely disappear locally; (4) then another slightly different community appears with single-level shifts in rank abundance (a), abundance demotions (b), and changes in numerical importance of the dominant organism. Finally, community (5) replaces community (4) during a sharp change in environmental contexts, leading to species turnover of nearly all taxonomic components of the antecedent community, including the replacement of dominant organism, D_1, by the new dominant organism, D_2.

near-normal marine salinity. As the Arapahoe-Newport barrier complex began to develop just to the east of the study area, geomorphic configuration of the coastline changed from that of an open embayment to a slightly restricted sound. Concomitant with a change in circulation patterns in this progressively more isolated estuarine basin was a gradual lowering of average salinity levels. At this point the open bay association was succeeded by a slightly restricted bay association in the vicinity of Beard Creek. This association is not as rich in species and not as diverse as the antecedent association, and reflects a community with slightly modified compositional and structural attributes.

As lagoonal sediments accumulated in what had gradually become a well-isolated backbarrier basin, the remains of a second, even less species-rich and diverse community were deposited. The restricted lagoonal association indicates an environment in which salinity levels reached their lowest on average, but probably fluctuated widely as a result of seasonal runoff from the mainland. Substrates had become less muddy, as shown by matrix surrounding fossils.

That circulation patterns again changed and occasional increases in average salinity occurred, probably linked to the opening, migration, and closing of tidal inlets in the Arapahoe-Newport barrier, are indicated by a moderately species-rich and diverse open lagoonal association near the top of the Beard Creek Member (Figure 5). This association exhibits preserved compositional and structural attributes similar, but not identical, to those of open and slightly restricted bay associations found at lower stratigraphic levels in the Flanner Beach. Detritus feeders were much less important in the open lagoonal association, however, because of changes from muddy sand to shelly sand substrates, and because of an increase in hydraulic energy related to shoaling and proximity to active inlets. Species-richness and diversity values are comparable to those of the open and slightly restricted bay associations because all three fossil associations were derived from communities that inhabited polyhaline waters. They differ enough in taxonomic composition, preserved trophic structure, and substrate types to be re-

garded as having been derived from slightly different, original communities.

V. MECHANISMS OF COMMUNITY REPLACEMENT

Long-Period, Subevolutionary, Community Temporal Dynamics. There seem to be two principal ways that replacement of communities could take place, depending upon rapidity and severity of habitat alteration. Sharp changes in local environments should eliminate most resident organism populations, and, when new environmental parameters are established, attritional replacement of communities through *species turnover* should occur. Very slow, continuous environmental alterations should lead to less catastrophic replacement sequences typified by *reorganization of species-abundance distributions* (see May, 1975) within established communities. Both turnover and reorganization probably operate together with one or the other mechanism being dominant in most types of changing environments.

R. G. Johnson (1972, p. 156-158) proposed a model of benthic community transition in shifting environments, adopted and elaborated by Rollins *et al.*, (1979), which described conceptually the mechanism of subevolutionary species turnover involving two adjacent, soft-bottom communities. Although Johnson regarded this type of change as a kind of environmentally-driven succession, it is a species-by-species turnover process (see Rollins *et al.*, 1979, p. 89-90). Hoffman and Narkiewicz (1977) discussed turnover in terms of developmental stages involving replacement of Paleozoic reefs. M. E. Johnson (1977) described water depth-controlled replacement of brachipods in Silurian benthic communities. A model proposed by Rollins and Donahue (1975) relates changing communities to transgressive-regressive depositional cycles, and is esentially a generalized conceptual model of replacement related to cycles of changing relative sea level. Rollins *et al.*, (1979) described changes in the composition and structure of their *Chonetinella-Septopora* Community, from the Upper Pennsylvanian Cambridge Limestone, as an example of succession. But this could be viewed alternatively as an example of gradual community

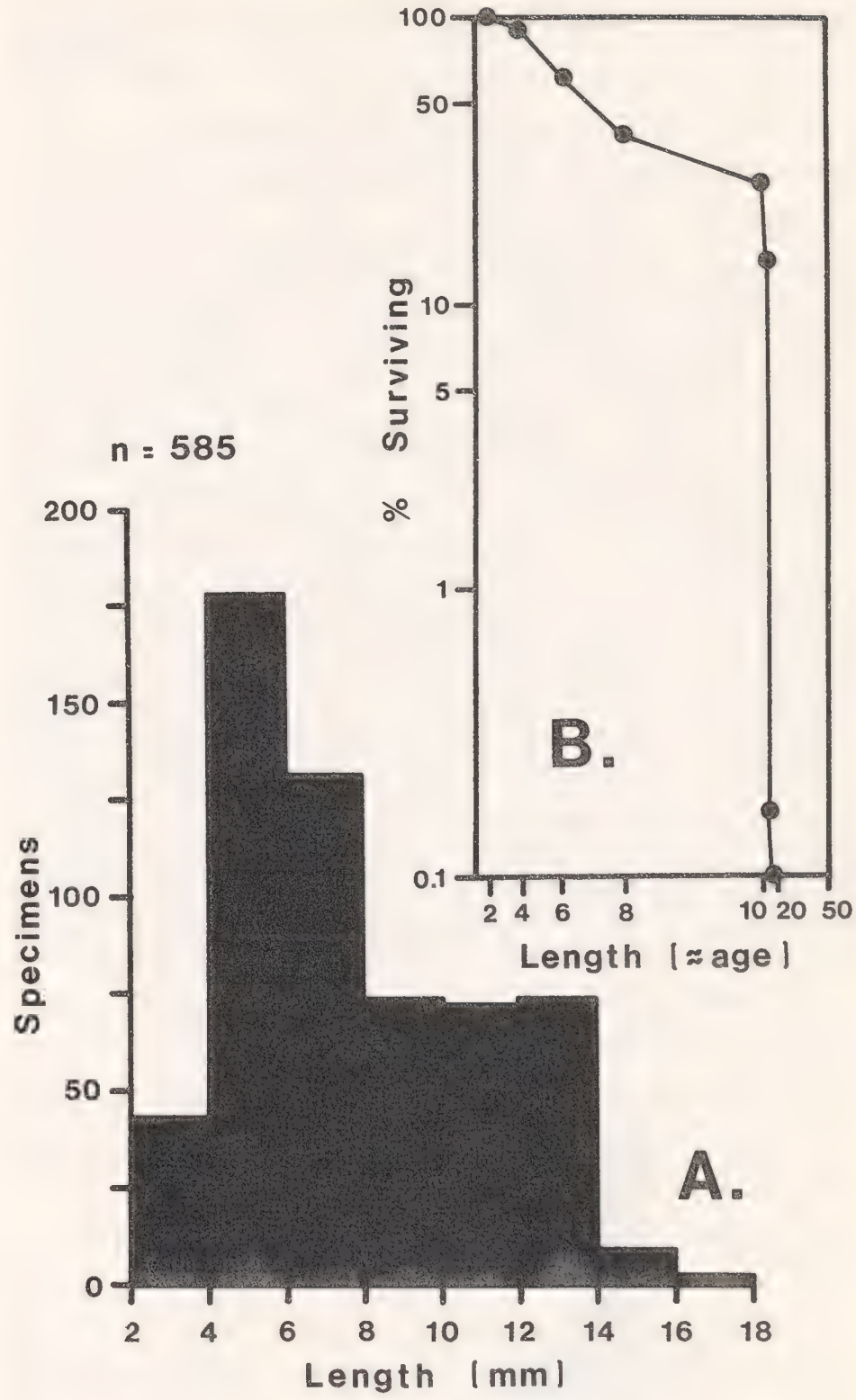

Figure 8. Normal population structure of *Mulinia lateralis* from a slightly restricted bay association (sample BC2-3, Figure 2). (A), size-frequency distribution of right valves; (B), survivorship curve based on (A) (both diagrams constructed using methods described by Dodd and Stanton, 1981). Compare with Figure 9.

replacement by reorganization considering the time-span and kinds of changes in faunal composition that were involved.

The community replacement sequence in the Flanner Beach Formation resulted mainly from reorganization, with some minor species turnover. Reorganization of species-abundance distributions that led to changes in community structure included at least four long-term, population level processes: (1) expansion and contraction in numerical dominance of the most abundant species, *Mulinia lateralis*, reflecting changes in relative environmental predictability, stability, and overall environmen-

tal rigor; (2) exchange of rank abundance levels by subdominant taxa (balanid barnacles, *Tellina texana, Ensis directus, Acteocina canaliculata*), perhaps reflecting changing importance of "equilibrium species" in successional sequences and probably changes in trophic resources; (3) promotions and demotions of numerically minor taxa, suggesting vagaries in larval recruitment patterns, changes in importance of normally sparse predatory snails, and rhythms in community complexity as reflected in species interaction patterns; and (4) continuous demotion through successively lower rank levels (*e.g., Nuculana acuta*), because of gradually changing trophic resources, changing states of physico-chemical limiting factors, or de-emphasis through time of certain ecologic associations (*e.g.*, predator-prey and competitive interactions) as important elements of community structure.

Turnover, by comparison, mainly resulted when environmental tolerance limits of species were closely approached or exceeded, and might have been caused by alterations in salinity, temperature, turbulence, physical and chemical properties of substrates, oxygen tension, or turbidity. Species turnover may also be linked to biologic changes in the environment, involving competitive exclusion, over-predation and local eradication, amensalistic interactions, or diseases, all brought about during juxtaposition and overlapping of once geographically discrete communities during gradual changes in habitat configurations. A model of community replacement by gradual reorganization is presented in Figure 7.

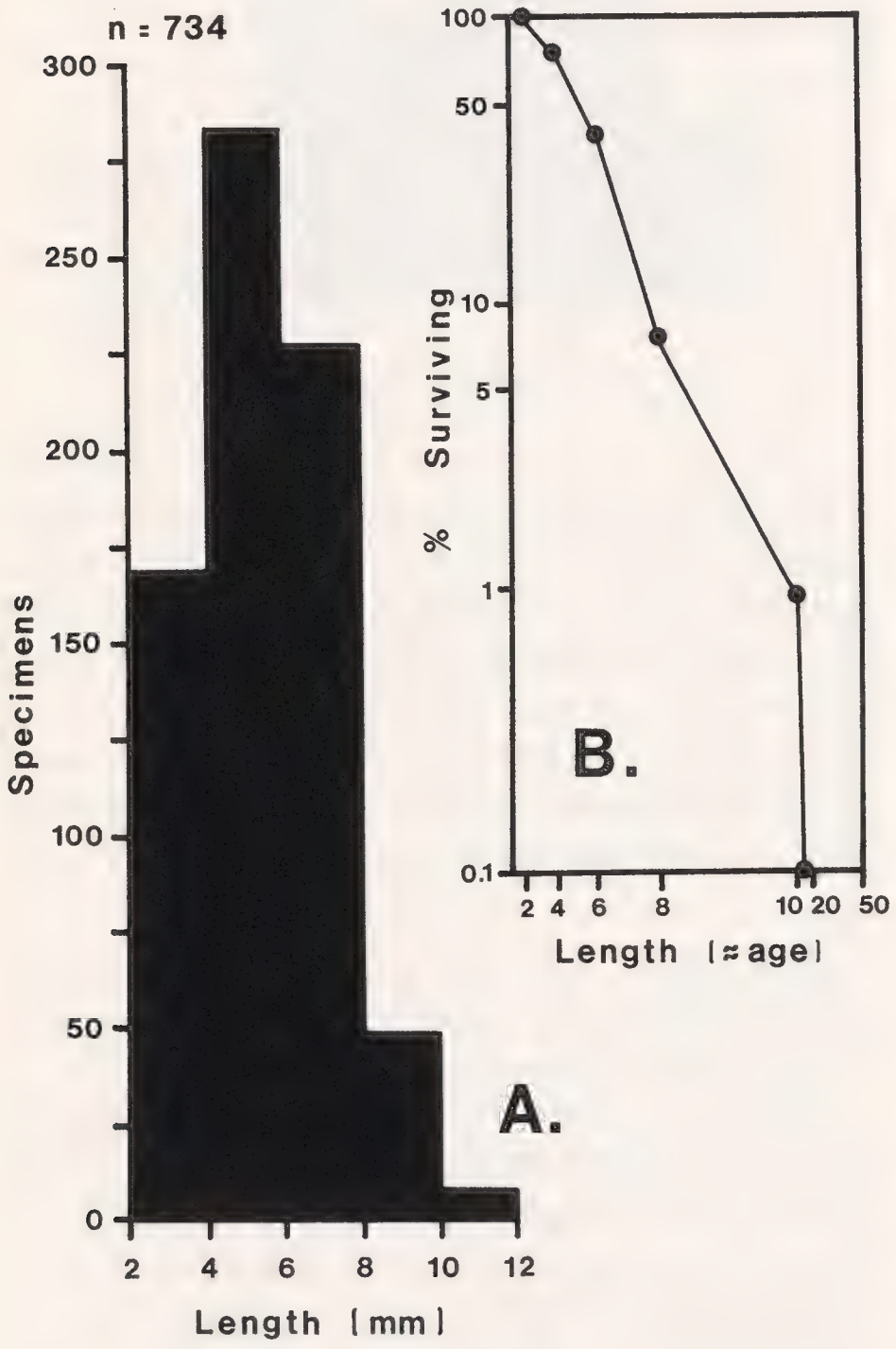

Figure 9. Normal population structure of *Mulinia lateralis* from a restricted lagoonal association (sample BC2-5, Figure 2). (A) size-frequency distribution of right valves; (B) survivorship curve based on (A).

Anatomy of a Single Step in the Flanner Beach Sequence. A sequence of three, vertically stacked shelly layers (minor simple shell beds) with intervening sparsely fossiliferous zones (samples BC2-3, BC2-4, BC2-5; Figure 2) straddles the transition from bay to lagoonal fossil associations. Sample BC2-4 contains a transitional fossil association with preserved compositional and structural attributes intermediate between associations at microstratigraphic levels immediately above and below it. If these minor simple shell beds represent single ecologic units or events (*i.e.*, condensed sere/pseudosere), then the detailed pattern of a step in the community replacement sequence can be analyzed by comparing the indigenous fauna of these three shelly layers.

Overall species richness declines gradually through the transition from 39 to 28 to 19 species; molluscan species richness follows a similar trend (32 to 25 to 18 species). Dominance among mollusks (Equation 1) increases gradually from 0.56 to 0.74 to 0.81; molluscan diversity (Equation 2) declines from 1.23 to 0.80 to 0.57. In descriptive trophic structure, the three samples plot close together near the infaunal corner of the substrate-niche diagram, and move gradually toward the suspension-feeding corner through the transition on the feeding behavior diagram (Figure 3).

Changes in dominance, diversity, and preserved trophic structure are largely the

result of *Mulinia lateralis* becoming increasingly more important in fossil associations through the transition. The preserved population structure of *Mulinia* also changes during replacement with juvenile mortality increasing, as reflected in size-frequency distributions of valves and survivorship curves based on normal populations (Figures 8, 9). Subdominant species undergo shifts in rank position through: (1) in some cases nearly exact exchanges between two faunal components (*Acteocina canaliculata*, a gastropod, and *Abra aequalis*, an infaunal detritus-feeding clam) come very close to trading ranks between samples BC2-3 and BC2-4); (2) gradual demotion in relative abundance (*Ensis directus* from 4.2% in sample BC2-3, to 1.7% in BC2-4, then to 0.5% in BC2-5); and (3) promotion of taxa (*Nassarius trivittatus*, a vagile detritus-feeding snail, from 0.1% in sample BC2-4 to 1.7% in BC2-5). Some numerically minor species in the slightly restricted bay association completely disappear during the transition. It is important to note that certain transitions involving changes in abundance of uncommon to rare taxa may have no significance as subevolutionary changes whatsoever, but may reflect a kind of bias resulting from short-term processes (*e.g.*, localized, short-lived outbreak of predatory snails with shells disproportionately added to an attritional fossil deposit). In the overall replacement sequence, as well as in this segment of the sequence, such "false signals" are controlled by considering varied lines of evidence for long-term changes.

In this well-preserved transition step, a gradual decrease in average salinity, more complete isolation from the natural physico-chemical buffering system of open shelf waters, and slight decrease in water depth probably acted together to decrease environmental stability and predictability on the local estuarine seafloor, and to increase spatial and temporal heterogeneity of resources. Trophic supplies may have been altered. The amplitude of seasonal changes and frequency of disturbances probably increased sharply. The resident fauna reorganized at the community level through changes in species-abundance distributions, deletion of some organism populations, slight modification of trophic structure, and overall decline in number of ecologic associations and community complexity.

VI. FUTURE RESEARCH INVOLVING REPLACEMENT

Future studies of community replacement should seek to identify both the mechanisms of faunal transitions, as well as the environmental factors that propelled the changes. If replacement really is one of the main reasons for subevolutionary changes in the composition of fossil deposits in vertical sequences located between stratigraphic breaks, then many examples of this phenomenon must be available for study in rocks of many different ages with varied paleoenvironmental histories. Replacement has been happening ever since organisms became associated within communities through overlapping environmental requirements and biotic interactions, and the record of replacement in protected environments should be well-preserved for skeletalized metazoans with populations affected by habitat alteration.

It would be extremely interesting to discover the relationships and linkages between replacement, and the processes that take place during ecologic succession, community response, and community evolution. Although different from community replacement, primary succession can be viewed as the initial step in the establishment of a new community in an area after species turnover processes, associated with sharp changes in environmental settings, have eradicated all previously established resident communities (as during a regression and subsequent transgression of a continental shelf sea, or similar drastic change in habitat [see Harland, 1981; Harris *et al.*, 1984]). Transspecific evolution, on the other hand, can be pictured as occurring in the contexts of changing communities that are subject to species turnover and species-abundance reorganization in subevolutionary time (Olson, 1952; Hoffman, 1983).

Investigations of modern examples of replacement should be undertaken to understand the processes that lead to species turnover and reorganization of faunas. Modern settings in which natural habitat alteration is reshaping composition and structure of communities could be targeted for long-term sampling surveys that aim to

trace the impacts of directional, long-period changes in environmental qualities. One example of a modern survey that would have an application in paleoecologic studies of backbarrier estuarine basins is the monitoring of community transitions within lagoons near short-lived tidal inlets that breach barrier islands, remain active for years to tens-of-years, then are closed or migrate. Of interest in modeling population-level mechanisms of replacement are the recent studies that involve artificial habitat alteration of diminutive ecosystems, such as small lakes and streams (Schindler *et al.*, 1985; Peterson *et al.*, 1985). But because of the long spans of time involved in development of most repalcement sequences, compared to the length of active careers of field ecologists, the study of community replacement falls more appropriately within the methodologic domain of the paleoecologist, whose business it is to evaluate fossiliferous sequences of sediments that have been compiled during thousands to millions of years.

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IX. APPENDIX
LOCALITY REGISTER

Locality numbers refer to measured sections shown in Figure 2. All fossils came from shell beds in the Beard Creek and Smith Gut members, in lower parts of bluff exposures at these localities.

BC1: Bluff, 0.6 km northwest of center of mouth of Beard Creek, at end of jeep trail about 0.3 km upstream from Whisk Point, north shore of Neuse River, southernmost Pamlico County, North Carolina; southeast corner, Upper Broad Creek 7.5' quadrangle.

BC2: Bluff, 0.3 km southeast of BC1 and 0.4 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore of Neuse River, southernmost Pamlico County, North Carolina; southwest corner, Arapahoe 7.5' quadrangle.

BC3: Bluff, 0.1 km east of BC2 and 0.3 km northwest of center of mouth of Beard Creek, at Whisk Point, north shore of Neuse River, southernmost Pamlico County, North Carolina; southwest corner, Arapahoe 7.5' quadrangle.

SG1: Bluff, 3.4 km southeast of center of mouth of Beard Creek and 0.3 km northwest of Smith Gut, north shore of Neuse River, southernmost Pamlico County, North Carolina; northwest part, Cherry Point 7.5' quadrangle.

REVIEW

SEDIMENTARY AND EVOLUTIONARY CYCLES, edited by Ulf Bayer and Adolph Seilacher. Lecture Notes in Earth Sciences, 1: Published by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, vi + 465 pp., illus., paper, $29.50

Twenty-two papers by thirty authors are presented in this volume, the printed proceedings of the symposium held at Tuebingen in September, 1983. Much of the content is concerned with the dynamics, immigration, and environmental evolution of faunas and their ecological patterns; other papers deal with dynamic stratigraphy and sea level changes.

—H.C.S.

OSTRACODE BIOSTRATIGRAPHY AND PALEOECOLOGY OF THE PLIOCENE OF THE ISTHMIAN SALT BASIN, VERACRUZ, MÉXICO

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I. ABSTRACT

A detailed systematic and cluster analysis study of samples from the Pliocene of the Isthmian Salt Basin, Veracruz, México, shows characteristic ostracode assemblages for the Encanto, Lower and Upper Concepción, and Agueguexquite strata, and a shallowing-upward trend during the Pliocene.

The Encanto strata, the oldest unit (N19 or upper N18), are characterized by *Ambocythere* spp., *Argilloecia posterotruncata, Bradleya normani, Krithe trinidadensis* and *Parakrithe* spp., indicating a middle to upper bathyal environment. The Lower and Upper Concepción beds (N19-20) can be recognized by the presence of *Actinocythereis vineyardensis, Touroconcha lapidiscola*, and the abundance of *Hulingsina* sp. 1, *Henryhowella* ex. gr. *asperrima*, and *Puriana* spp. Encanto species persisting in the Lower Concepción beds indicate an upper bathyal to outer neritic environment. The Upper Concepción beds lack these species but instead possess abundant *Cyprideis* and *Perissocytheridea* spp., *Basslerites*? sp., *Malzella conradi* and *Echinocythereis margaritifera*. The Upper Concepción assemblage indicates an outer to middle shelf environment. The Filisola and Paraje Solo samples were barren of ostracodes. Their foraminiferal and mollusk fauna indicates nearshore and brackish environments. The Paraje Solo may be in part contemporaneous to the Agueguexquite. The Agueguexquite strata contain the youngest (middle N20), most abundant, and diverse fauna, indicating an inner neritic environment of deposition and representing a local marine transgression of short duration in the northern part of the basin. By upper Agueguexquite time brackish and continental conditions returned.

II. INTRODUCTION

The Isthmian Salt Basin is located in the states of Veracruz and Tabasco, México, between longitude 93°30′ and 95°10′W and from latitude 17°40′N to the Gulf of México, covering approximately 10,500 km^2 (Fig. 1). It is one of the major oil producing regions of México and detailed knowledge of its sediments is of great economic importance. From the geological point of view, it also represents a very interesting area as it shows a complex history influenced by the opening and evolution of the Gulf of México Basin and the development of the Middle American volcanic arc. As a consequence of this tectonic activity, great amounts of sediments and a rapid succession of environments are present in the basin. The recognition and understanding of these environments is of both scientific and economic importance.

Numerous studies of foraminifera, especially benthic ones, have been conducted

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Figure 1. Location map of México.

in the area; however, other microfossil groups are poorly known. The only study on ostracodes is a checklist of 32 species (Bold, 1978).

The samples used in this study were collected from Pliocene outcrops east and west of the Coatzacoalcos River, Veracruz (Fig. 2). Additional samples were provided by Dr. B. Kohl of Chevron Oil Company, by Dr. W. A. van den Bold of Louisiana State University and Drs. H. E. and E. H. Vokes of Tulane University. Sample locations and measured stratigraphic sections are shown in figures 3, 4, 5, 8, and 9 respectively; a list of locations and a list of species is given at the end of the paper.

III. ACKNOWLEDGMENTS

This study was made possible by the Universidad Nacional Autónoma de México, which supported the research and field collections. The writer wishes to acknowledge all the persons who were involved, primarily Ing. D. Córdoba, Dr. J. Guerrero, and especially Mr. R. Gío-Argáez, who introduced me to the subject and assisted in the fieldwork.

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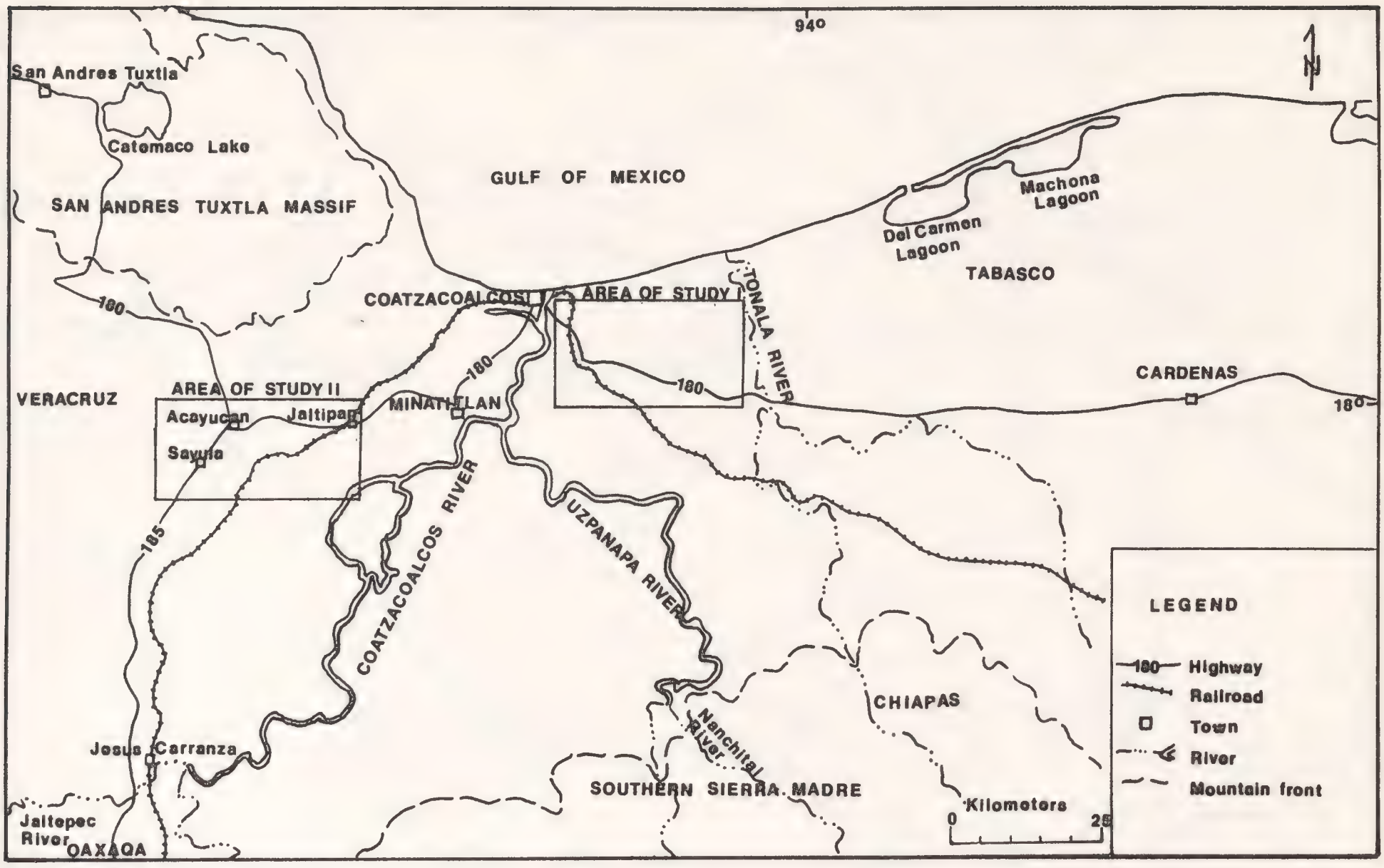

Figure 2. Location map of study area.

Ghiold and G. Rountree for their help with the word processor, and to E. Heydari and J. Dyson for drafting some of the figures and revising the manuscript.

IV. BIOSTRATIGRAPHY AND PALEOECOLOGY

The sediments outcropping in the Isthmian Salt Basin range from Triassic-Jurassic to Recent. The oldest units occur in the south in the Sierra Madre and the youngest to the north in the Gulf Coastal Plain. This study is confined to the Pliocene strata of the Basin.

The Pliocene deposits consist of the Encanto, Lower and Upper Concepción, Filisola, Paraje Solo, Agueguexquite, and Cedral "formations." As noted by other authors (Contreras, 1959, p. 411; Sansores adn Flores-Covarrubias, 1972, p. 6; Kohl, 1985, p. 5; Akers, 1981, p. 145), the term *Formation* is improperly used in the Basin for Neogene strata because they have been defined on paleontological not lithological basis. Most are therefore not mappable field units. However, they are widely cited in the literature and in the oil industry and for comparative purposes they will be referred here as "formations."

The environment and age determinations of the four fossiliferous units in the Isthmian Salt Basin (Fig. 6) indicate a gradual shallowing of the Basin from the upper middle bathyal (upper N18 - N19, Encanto) through upper bathyal – outer neritic (N19-20, Lower Concepción), through outer - middle neritic (N20, Upper Concepción), to inner neritic (N20, Agueguexquite).

However, between Upper Concepción and Agueguexquite beds we find Filisola of age N20 and Paraje Solo (brackish-continental) of unspecified age. This indicates a rapid uplift at the end of Concepción time (no inner neritic deposition) in the central and northern portion of the basin. By early Agueguexquite time a shallow, locally restricted transgression occurred, and by late Agueguexquite and Cedral times the brackish-deltaic depositional conditions returned.

ENCANTO (Gibson, 1936).

The Encanto strata represent the oldest unit sampled in this study. The lithology consists mainly of bluish-gray to yellowish-gray, fine-grained sandstone and silty clay, generally well stratified and up to 800 m

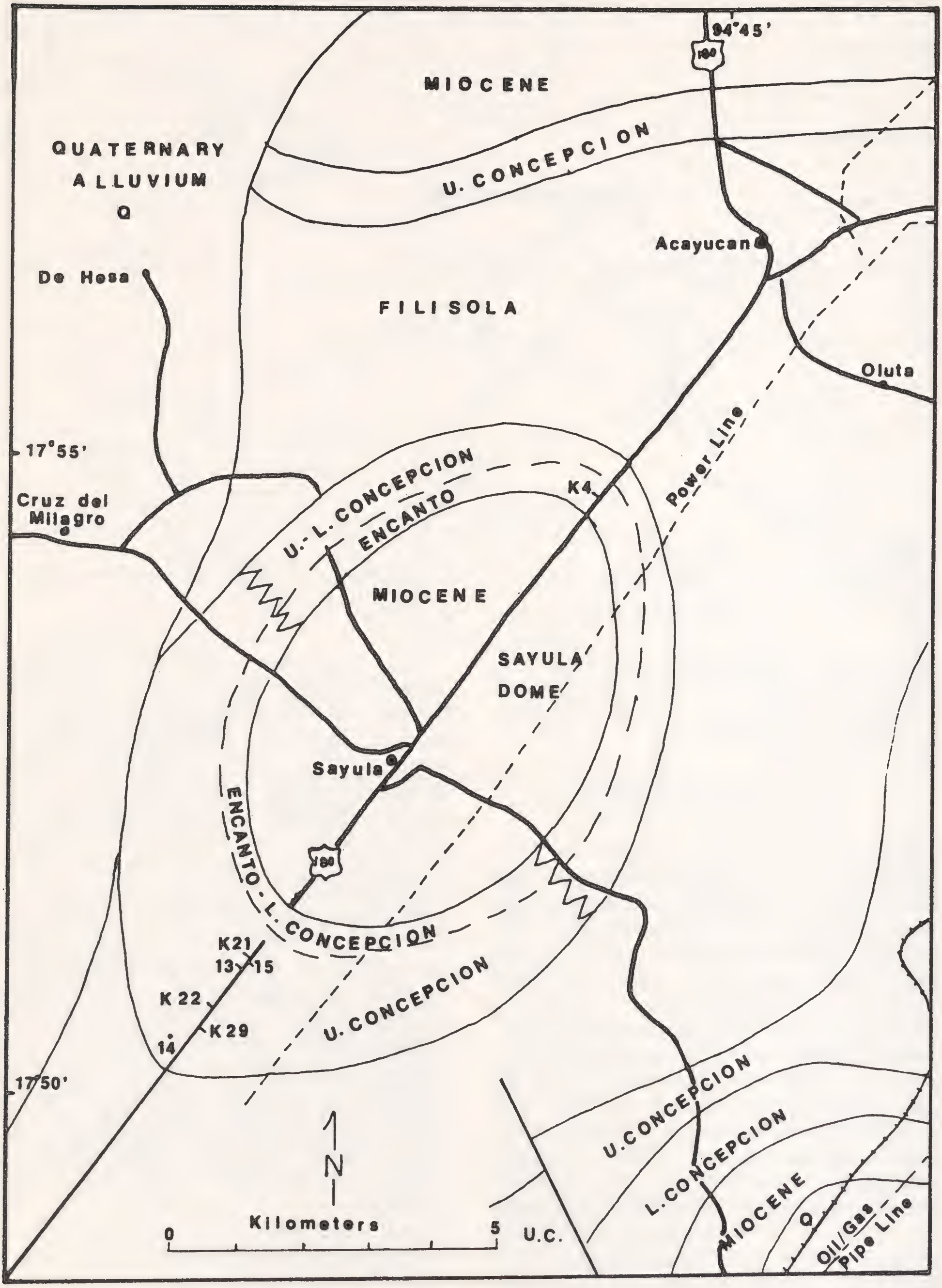

Figure 3. Geologic map and location of samples across Sayula Dome (after Kohl, 1985).

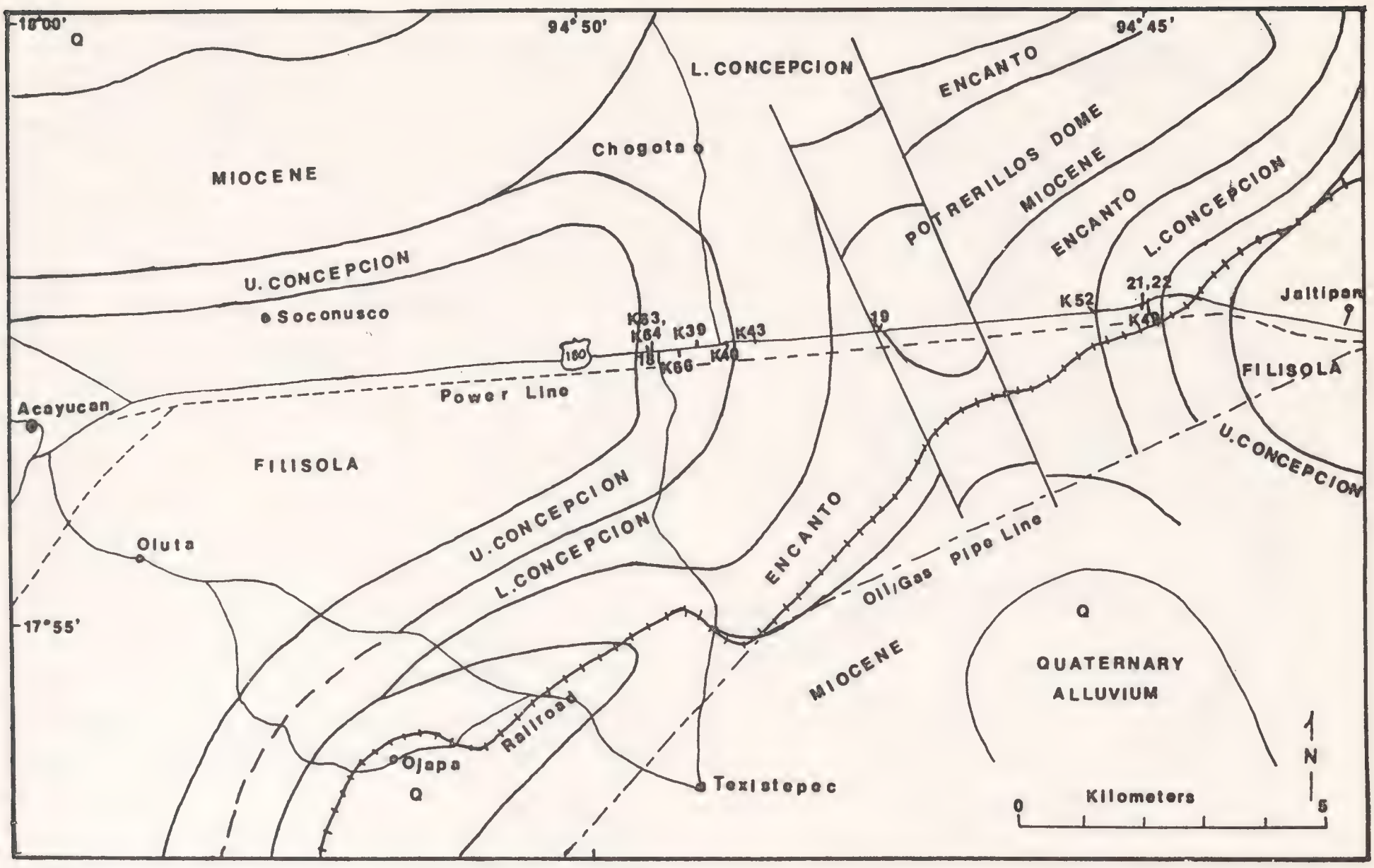

Figure 4. Geologic map and location of samples across Potrerillos Dome (after Kohl, 1985).

thick (Benavides, 1956). In the area of study these sediments generally consist of calcareous silty shale. The Encanto beds were assigned by Gibson (1936) to the Lower Miocene, were placed in the Middle Miocene by Sansores and Flores-Covarrubias (1972) and Akers (1972, 1979), and in the Lower Pliocene by Kohl (1985) and Akers (1984). Only a few samples from this unit yielded ostracodes: K4, (Fig. 3), K52, 19 (Fig. 4), 78, and 60 (Fig. 5).

Species characteristic of this "formation" are: *Krithe trinidadensis, Argilloecia posterotruncata, Parakrithe* spp., *Ambocythere* spp., *Bradleya normani*, and *Xestoleberis* sp. 2.

Age.

The presence of *Ambocythere caudata* (Early Pliocene to Recent), *Cytheropteron? yorktownensis* (Early Pliocene-Late Pleistocene), *Bairdoppilata* sp. aff. *B. victrix* (Pliocene), and *Parakrithe* sp. 2 (Early to Middle Pliocene), indicates an Early-Middle Pliocene age.

According to Kohl (1985) the planktonic foraminifer *Globigerina nepenthes* Todd "does become extinct near the top of the Encanto strata." Berggren (1973) placed the extinction of this species in the Lower Pliocene (later portion of Neogene Zone N19 of Blow, 1969) and assigned an age of 3.7 m.y. to it. Akers (1984) examined sample TU 1153, collected close to sample 19 of this study, and found a rich planktonic flora and fauna typical of the Lower Pliocene. He indicates that "the coincidence of *Globigerina nepenthes* with *Globorotaloides hexagona* and *Globigerinella calida* indicates a stratigraphic position in Zone N19 or the upper part of Zone N18."

Environment.

The environment of deposition can be deduced by the following species:
(1) *Krithe trinidadensis* has been recorded in upper to middle bathyal environments in the modern Caribbean. Although this species is also common in the Concepción strata, it is by far most abundant in the Encanto. Only one specimen has been recovered from the Agueguexquite beds.
(2) *Parakrithe* sp. 1 is a common species in the Encanto. Although it also occurs sparsely in the Lower Concepción, its peak

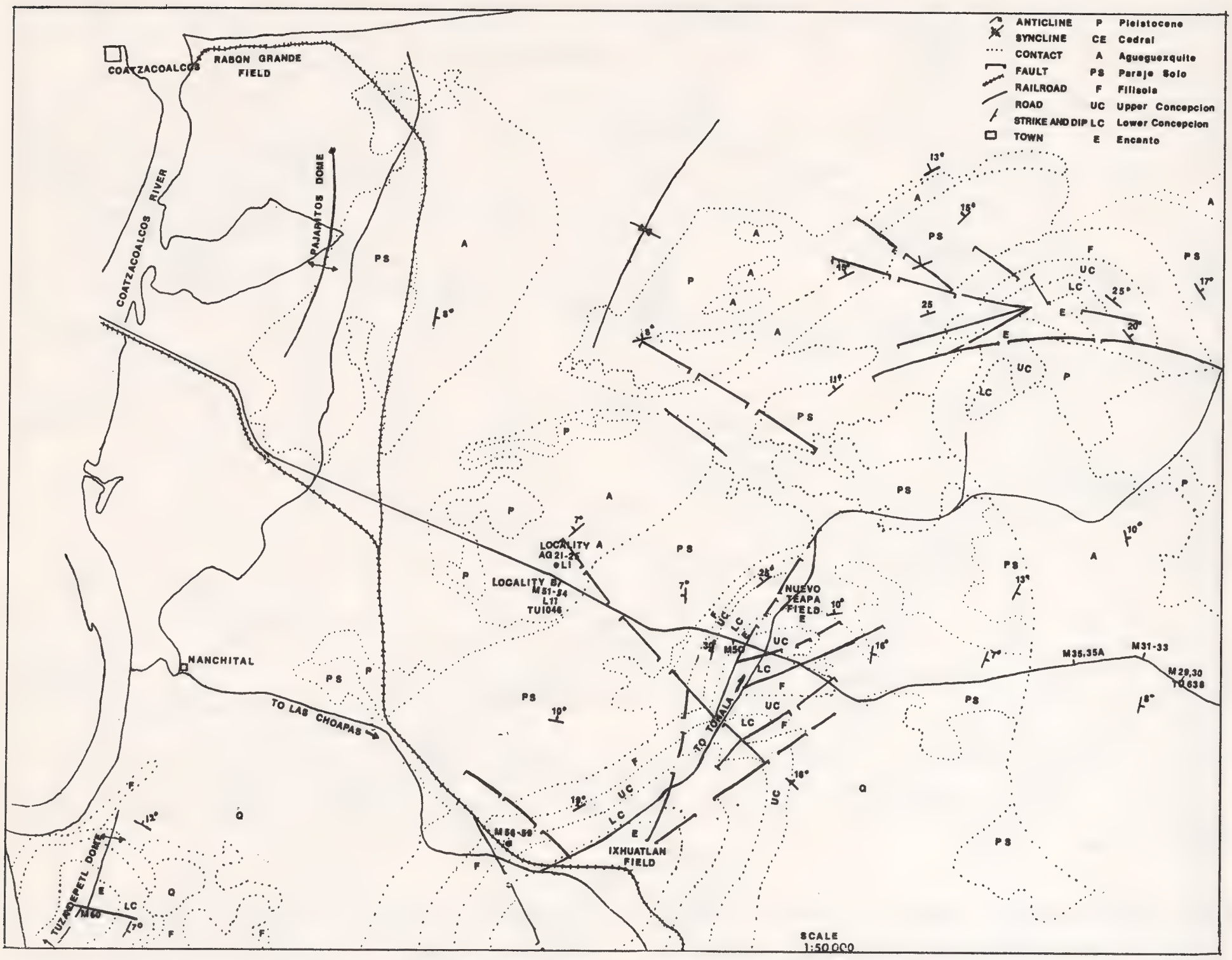

Figure 5. Geologic map and location of samples in eastern study area.

abundance is in the Encanto. It occurs only in a set of successive, closely spaced samples from the eastern flank of the Sayula Dome (Fig. 3), and its abundance increases towards the base of the section (increasing depth). *Parakrithe* sp. 1 is found in the Caribbean (Dominican Republic) Pliocene in probably upper slope sediments (Bold, per. comm.).

(3) *Parakrithe* sp. 2 is less abundant than *P.* sp. 1, but it is restricted almost exclusively to this unit; only two other specimens have been found in Lower Concepción strata. Van Morkhoven (1972) records this genus in the Recent Gulf of México from outer neritic to upper slope.

(4) *Argilloecia posterotruncata* is a species that occurs in all the units; however, it is very rare in Agueguexquite, rare in Concepción and has its peak abundance in Encanto beds, where it is a common species. *Argilloecia posterotruncata* is characteristic of middle - outer neritic to upper slope environments in the Caribbean Miocene to Recent.

(5) *Ambocythere caudata* and *Ambocythere* sp. cf. *A.* sp. *A* of Cronin (1983) have been reported by Bold and Cronin respectively from middle to upper slope environments in the Recent North Atlantic, and both are restricted to the Encanto, except for one specimen found in the Lower Concepción.

(6) *Bradleya normani* is a modern bathyal species (Benson, 1972) and it is found only in this unit. The presence of these species indicates an upper to middle slope environment for the Encanto strata.

The upper to middle slope character of the ostracode fauna is corraborated by the benthic foraminifera. Sansores and Flores-Covarrubias (1972) considered the depth of deposition of these beds to be between 500 and 2000 m. Kohl (1985) indicates that "the benthic foraminiferal assemblages of the Encanto 'biozone' imply ancient water depths of 300 to 700 m (upper to middle

bathyal)."

An exception to the indicated depth is sample K4. According to Kohl (1985), this sample exhibits a faunal mixing of near-shore benthic foraminifera and upper bathyal ones, as well as reworked species of older, Middle Miocene, sediments. Interpretation of the ostracode assemblage shows a similar mixing. *Malzella conradi* is the most abundant species in the Isthmian Salt Basin. In the Encanto strata it is exclusively found in sample K4 except for one specimen found in sample 19. *Malzella conradi* has a stratigraphic range from Late Miocene to Late Pliocene, and it is found in strata interpreted as shallow shelf deposits by several authors; therefore, it seems that, along with the redeposition of older sediments there was also contemporaneous contamination at this locality, probably due to slumping of shallow shelf sediments.

Other species also considered as shelf indicators whose presence in Encanto is restricted to K4 include: *Radimella confragosa*, *Quadracythere? compacta*, *Paracytheridea tschoppi*, *Loxoconcha* sp. aff. *L. helenae*, *Mutilus?* sp., *Caudites nipeensis*, *Munseyella bermudezi louisianensis*, and *Buntonia* sp.

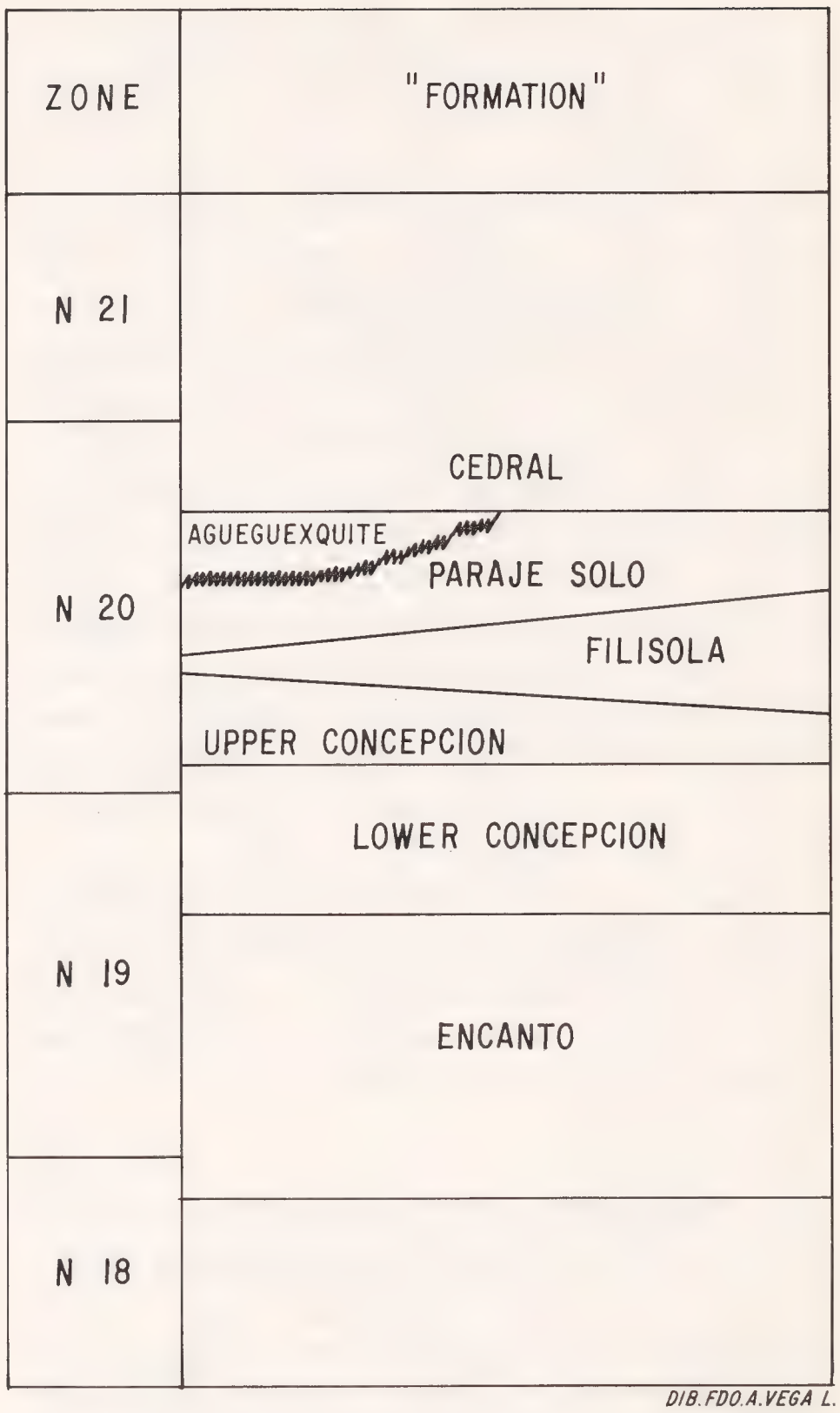

Figure 6. Stratigraphic column of the Pliocene sediments in the Isthmian Salt Basin (see text for lithology and thicknesses).

LOWER CONCEPCIÓN (Gibson, 1936).

Beds of the Lower Concepción consist of approximately 450 m of very fossiliferous gray and blue, poorly stratified silty shales with sandy layers of different thickness toward the top. This "formation" grades into the Upper Concepción; the contact between the two units is determined solely by microfauna. These strata contain a more diverse and abundant fauna than the Encanto: 55 species belonging to 36 genera were identified in the Lower Concepción. The most abundant are: *Henryhowella* ex. gr. *asperrima*, *Puriana* spp., *Echinocythereis* sp., *Hulingsina* sp. 1, and *Basslerites minutus*. Most of these species are characteristic of shelf environments. No species are restricted to these beds; however, some are restricted to Concepción strata (Lower and Upper): *Actinocythereis vineyardensis*, *Caudites rectangularis*, *Haplocytheridea-Peratocytheridea* molts, *Hulingsina* sp. 3, *Loxoconcha matagordensis*, *Perissocytheridea subrugosa*, and *Touroconcha lapidiscola*. Most of these are less abundant in the Lower than in the Upper Concepción.

Lower Concepción beds can be distinguished from Upper Concepción by the absence of certain species (see ,Upper Concepción), the smaller number of brackish water species and the presence of deeper water forms common in the Encanto (*Ambocythere caudata*, *Parakrithe* spp. and *Cytherella* sp. aff. *C. hannai* var.) that have their last appearance in the Lower Concepción.

Age.

The age indicated by the ostracode assemblage is not older than Early Pliocene, as determined by the following species: *Pterygocythereis inexpectata*, *Perisso-*

caudata (Early Pliocene-Recent), *Cytheropteron? yorktownensis* (Early Pliocene-Late Pleistocene) and *Parakrithe* sp. 2 (Early to Middle Pliocene).

Kohl (1985) reports the presence of *Globorotalia margaritae* Bolli and Bermúdez, *Sphaeroidinellopsis seminulina* (Schwager) and *S. subdehiscens subdehiscens* (Blow). According to Berggren and van Couvering (1974), *G. margaritae* has its last ocurrence at the top of zone N19 and *S. seminulina* at the end of N20. Akers (1981, fig. 1), however, indicates that *G. margaritae* and *S. subdehiscens subdehiscens* have their last ocurrences in the late N20. Akers (1979) studied the planktonic fauna and flora at TU 1025 and reported that "the occurrence of *Globorotalia (Turborotalia) acostaensis pseudopima* Blow, *Reticulofenestra pseudoumbilica* (Gartner), *Pseudoemiliania lacunosa* (Kampter) and *Sphenolithus abies* Deflandre dates the Lower Concepción beds at TU 1025 as Middle Pliocene, zone N20."

Environment.

Most of the ostracode species in these beds range from outer neritic to inner-middle neritic environments (*i.e., Actinocythereis vineyardensis, Pterygocythereis inexpectata* etc.) and a few represent upper bathyal depths (*i.e., Ambocythere spp., Henryhowella* ex. gr. *asperrima, Parakrithe* spp., etc.). The absence or decreased abundance of upper slope species and the presence of characteristic shelf forms indicate that these strata were deposited at shallower depths than the underlying Encanto beds. On the other hand, the presence of the upper slope species and the comparatively small numbers of inner-middle shelf species indicate that the Lower Concepción deposits are deeper than those of the overlying Upper Concepción, and probably represent upper bathyal to outer neritic environments.

These conclusions are supported by a study of the benthic foraminifera by Sansores and Flores-Covarrubias (1972), who concluded that these beds were deposited between 200 and 500 m of depth (outer shelf to upper slope). Kohl (1985) suggests a water depth of 180-200m (outer neritic to upper bathyal) for these strata.

UPPER CONCEPCIÓN (Gibson, 1936).

Lithologically this unit consists mainly of massive grayish-blue silty clay, similar to that of the Lower Concepción, with occasional calcareous concretions. The sequence is about 200 m thick. Its lower and upper contacts are gradational; more shaley toward Lower Concepción and sandier toward Filisola; they are recognized solely by microfossils. The ostracode fauna does not contain a group of restricted species as the Encanto and Agueguexquite do; however, some species are more abundant here than anywhere else. These include *Hulingsina* sp. 1, *Basslerites minutus, Henryhowella* ex. gr. *asperrima* and *Haplocytheridea-Paratocytheridea* molts. The abundance of these species and the presence of *Malzella conradi, Echinocythereis margaritifera, Basslerites*: sp., etc., distinguish these beds from the Lower Concepción ones.

Age.

The age of the "formation" can be determined by the ostracode species *Perissocytheridea subrugosa, Pterygocythereis inexpectata, Cytheropteron? yorktownensis* and *Cyprideis mexicana*, which indicate an age of Early Pliocene or younger for these beds. An important species is *Loxoconcha* sp. *A.* (Hazel, 1977) that has only been found in zones N19 and N20 in Florida, North Carolina and Virginia.

Kohl (1985) found in these beds the planktonic foraminifera *Globorotalia margaritae, Sphaerodinellopsis seminulina* and *S. subdehiscens* and the calcareous nannoplankton *Sphenolithus abies. Sphaerodinellopsis subdehiscens* suggests a Middle Pliocene age, Neogene zone 20 of Blow (1969). *Sphenolithus abies* became extinct at about the middle portion of zone N20 (Blow, 1969) and *S. subdehiscens* became extinct at about 3.0 m.y.a. (Berggren, 1973). Therefore, the age of this unit should be the early part of Blow's zone N20 and slightly over 3.0 million years.

Akers (1979, 1981) also places this fauna in zone N20, based on the concurrence of the calcareous nannoplankton species *Pseudoemiliania lacunosa, Reticulofenestra pseudoumbilica* and *Sphenolithus*

abies. He indicates that there is little if any difference between this assemblage and the one found in Lower Concepción.

Environment.

Most of the species found in these strata are characteristic of outer to middle shelf. The absence of deeper water species that occur last in the Lower Concepción suggests that these beds were deposited at shallower water depth than those of the Lower Concepción. The absence of inner neritic species found in the Agueguexquite strata, and the presence of *Henryhowella* ex. gr. *asperrima* and *Actinocythereis vineyardensis* indicate that these beds were deposited under deeper water conditions than the Agueguexquite beds.

However, there are several brackish water species found in these strata. *Cyprideis* sp. cf. *C. mexicana, C. salebrosa, Loxoconcha matagordensis* and *Megacythere repexa* are very rare, not more than three specimens per sample. *Perissocytheridea bicelliforma* and *P. subrugosa* are more abundant; however, they are mainly molts and badly preserved, which suggests an allochthonous origin from nearby low salinity environments.

The presence of brackish water species in the Concepción may be due to proximity of the area of deposition to a river mouth, to its location in the pathway of water currents bringing water and sediments from a river and marginal bays, or to slumping on a relatively narrow, steeply sloping shelf.

The outer to middle neritic environment of deposition suggested by the ostracode assemblage is also indicated by the foraminiferal fauna. Sansores and Flores-Covarrubias (1972) stated that the Upper Concepción strata were deposited between 100 and 200 m depth (middle to outer neritic), and Kohl (1985) determined a paleodepth of 50 to 180 m.

Age.

The following ostracode species indicate a Pliocene age (N19, N20) for these strata: *Pterygocythereis inexpectata, Kangarina ancyla* (Early Pliocene-Recent); *Cytheropton? yorktownensis, Microcytherura choctawhatcheensis* (Early Pliocene to Late Pleistocene); *Bairdoppilata* sp. aff. *B. victrix* (Pliocene) and *Loxoconcha* sp. *A* (N19 - N20).

Hazel (1983) indicated that the Yorktown Formation of North Carolina, which contains several of the most comon species of the Mexican Pliocene, is included in the *Orionina vaughani* Assemblage zone (N19-N20) with an age between 3.7 and 4.8 m.y. Cronin *et al.* (1984) extended the range of river and marginal bays, or to slumping on a relatively narrow, steeply sloping shelf.

The outer to middle neritic environment of deposition suggested by the ostracode assemblage is also indicated by the foraminiferal fauna. Sansores and Flores-Covarrubias (1972) stated that the Upper Concepción strata were deposited between 100 and 200 m depth (middle to outer neritic), and Kohl (1985) determined a paleodepth of 50 to 180 m.

FILISOLA (Gibson, 1936).

This unit consists mainly of 250 to 400 m of thick, fine- to coarse-grained quartzose sandstone beds, with sparse, thin, intercalations of soft bluish-gray shale toward the bottom. Fossils are rare and poorly preserved. As noted above, its contact with the Upper Concepción is transitional.

The samples collected from the Filisola strata were barren of ostracodes. However, scarce foraminiferal faunas reported by Sansores and Flores-Covarrubias indicate that these beds represent coastal deposits with deltaic influence. Akers (1979) examined a sample from the marine facies of this "formation" (TU 1141) outside the study area, near San Andrés Tuxtla, Veracruz (Fig. 2), and concluded that "the conjunction of *Globigerina bulloides apertura* Cushman, *Sphenolithus abies*, *Gephyrocapsa caribbeanica* Boudreaux and Hay and *Pseudoemiliania lacunosa* fixes the age of the Filisola Formation at the proposed type locality as middle Pliocene, Neogene zone 20."

PARAJE SOLO (Gibson, 1936).

This unit consists of 300 to 600 m of massive, thick, fine to coarse-grained sandstone with intercalations of silty clays and lignitic layers. It occasionally has a rare fauna of benthic foraminifera (*Elphidium* spp., *Ammonia becarii* Linné, *Eponides antillarum* (d'Orbigny) and mollusks, but most of the beds do not contain any fossils. It is considered to have been deposited under brackish or even freshwa-

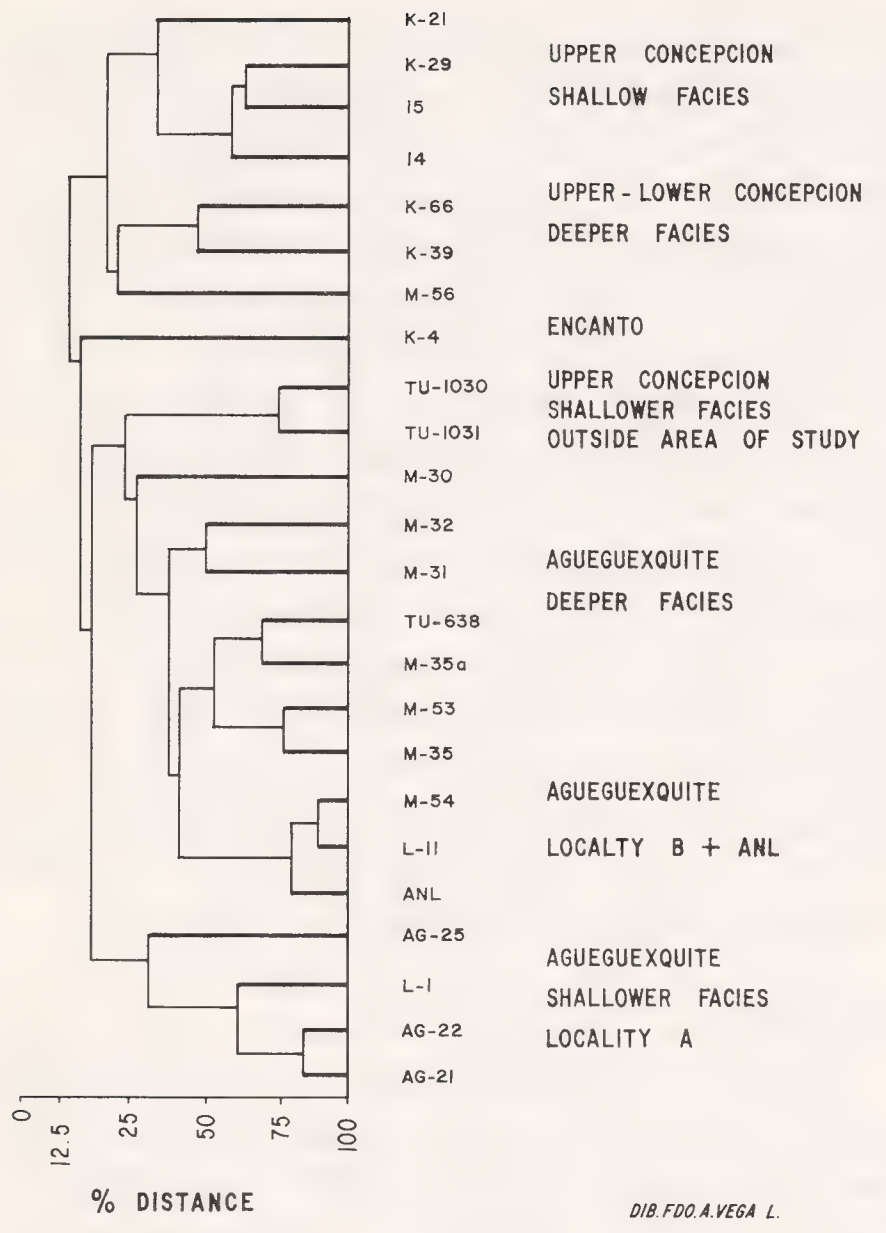

Figure 7. Cluster analysis dendrogram.

ter conditions. No ostracodes were found in these strata.

AGUEGUEXQUITE (Thalmann, 1935).

The Agueguexquite strata represent the last transgressive-regressive cycle and the end of marine deposition in the Isthmian Salt Basin. The unit consists of basal conglomerate, rich in microfauna, marine sands and silty shales that give way to continental lignitic sands and shales at the top. Five hundred meters of sediments have been reported in the subsurface. Only the lower part of the formation, including the basal conglomerate, yielded ostracodes, and presents the most diverse and abundant fauna: 63 species were identified. Of these, 20 are restricted to these beds: *Actinocythereis* sp. cf. *A. gomillionensis*, *Bairdia* sp. aff. *B. longisetosa* (except for one specimen in Upper Concepción), *Bairdoppilata* sp. aff. *B. victrix* (except for two specimens in K4), *Bairdoppilata* sp., *Cytherella vermilionensis*, *C.*, sp. aff. *C. pulchra*, *Cytherelloidea umbonata*, *C.* sp. cf. *C. umbonata*, *Cytheretta anderseni*, *Cytherura wardensis* (except for one specimen in Upper Concepción). *C.* sp. *A.*, *Gangamocytheridea? plicata*, *Hulingsina* sp. 2, *Kangarina ancyla*, *Loxoconcha wilberti*, *Luvula gigarton*, *Macrocyprina propinqua*, *Microcytherura choctawhatcheensis* and *Paracypris* spp.

Age.

The following ostracode species indicate a Pliocene age (N19, N20) for these strata: *Pterygocythereis inexpectata*, *Kangarina ancyla* (Early Pliocene-Recent); *Cytheropton? yorktownensis*, *Microcytherura choctawhatcheensis* (Early Pliocene to Late Pleistocene); *Bairdoppilata* sp. aff. *B. victrix* (Pliocene) and *Loxoconcha* sp. *A.* (N19 - N20).

Hazel (1983) indicated that the Yorktown Formation of North Carolina, which contains several of the most comon species of the Mexican Pliocene, is included in the *Orionina vaughani* Assemblage zone (N19-N20) with an age between 3.7 and 4.8 m.y. Cronin *et al.* (1984) extended the range of this zone to N21 with an age between 4.0 and 2.5 m.y.

Akers (1972) and Akers and Koeppel (1973) studied the planktonic fauna and flora of the Yorktown and Agueguexquite formations and found them very close in age and dated them as Zone N20 or top N19. Akers (1979, 1981) suggested that the presence in the Agueguexquite Formation of the nannoplankton species *Pseudoemiliania lacunosa*, *Reticulofenestra pseudoumbilica*, *Gephyrocapsa caribbeanica* and the absence of *Sphenolithus abies* indicate that "these beds were deposited just subsequent to the extinction of *R. pseudoumbilica* which may have occured higher in zone N20."

Berggren (1973) assigned an age of 3.0 m.y. to the extinction of *Sphaerodinellopsis subdehiscens*, which according to Kohl (1985) is approximately equivalent to the extinction of *S. abies*.

Environment.

The species found in these strata are characteristic of neritic environments and most of them decrease in abundance or are even absent in stratigraphically lower (deeper) units.

Malzella conradi is typically found in shallow water neritic environments. Hulings (1967) considered *M. conradi* along with *Cytherura wardensis*, *Bairdia gerda* (here *B. longisetosa*), *Pellucistoma mag-*

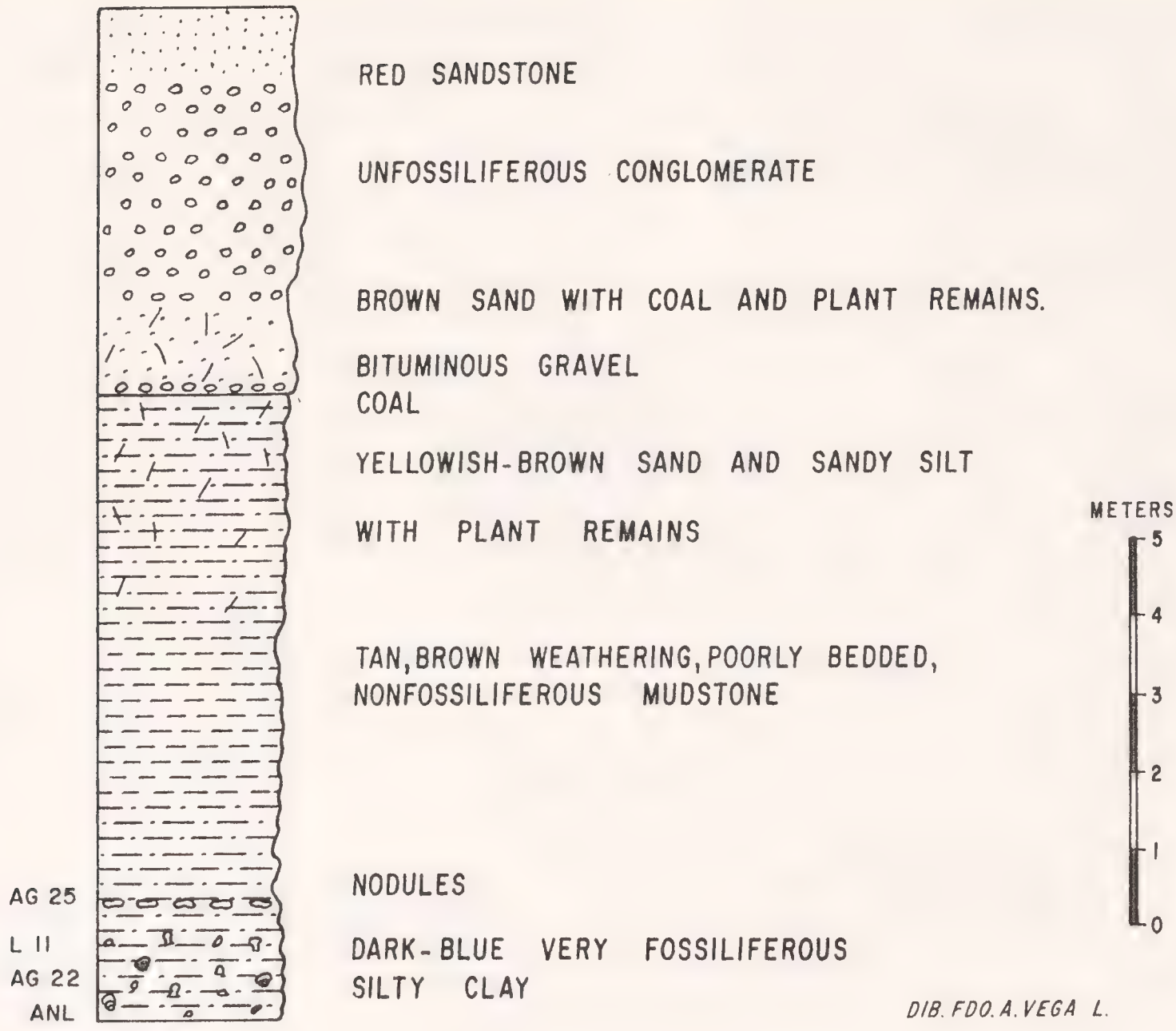

Figure 8A. Stratigraphic section of the Agueguexquite strata in locality *A* (pipeline), showing part of the lower to upper members of the "formation" and part of the Cedral Formation (see Fig. 5 for map location).

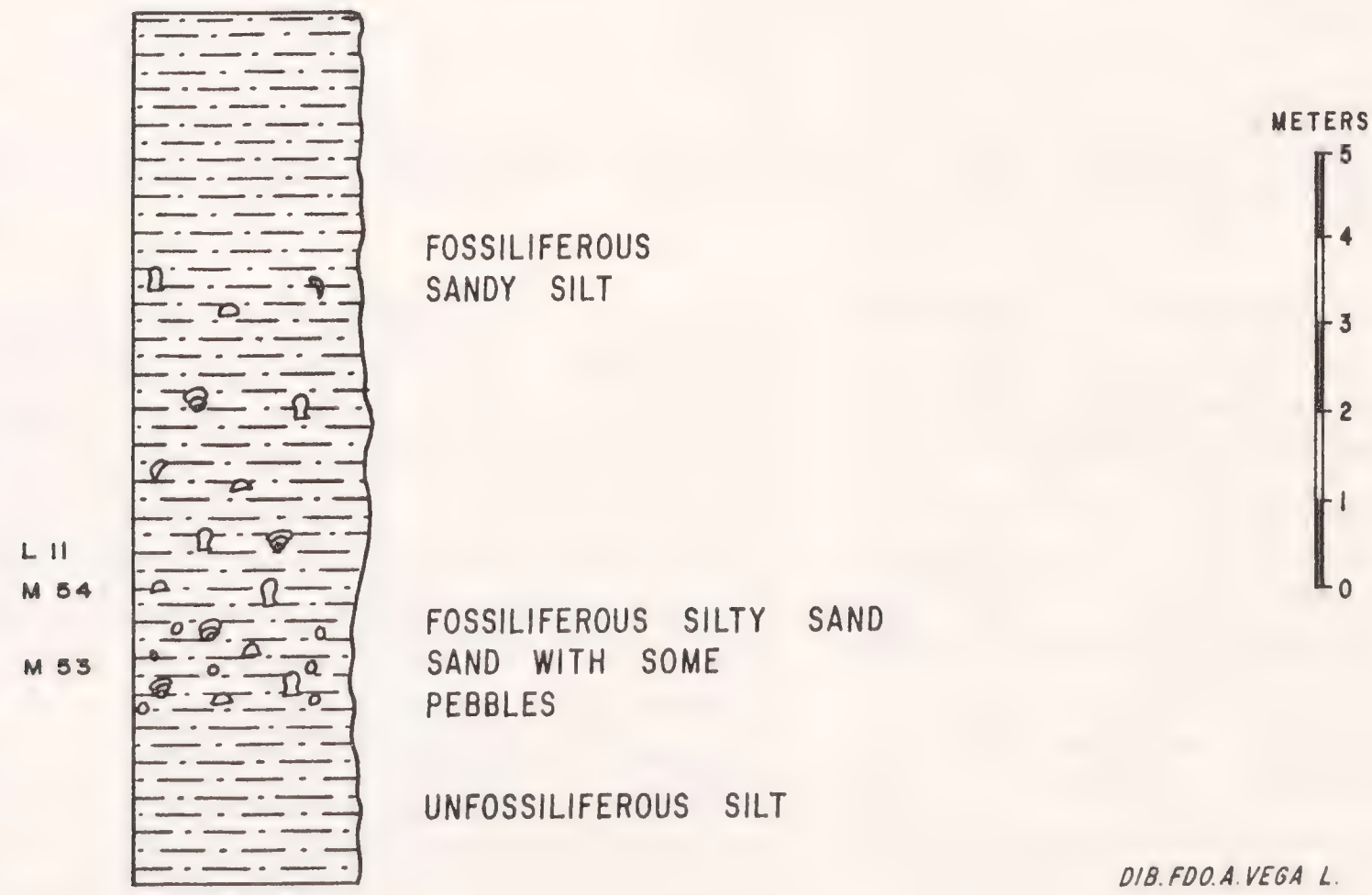

Figure 8B. Stratigraphic section of the lower strata at locality *B* (México Highway 180), showing part of the lower to middle Agueguexquite Formation (see Fig. 5 for map location).

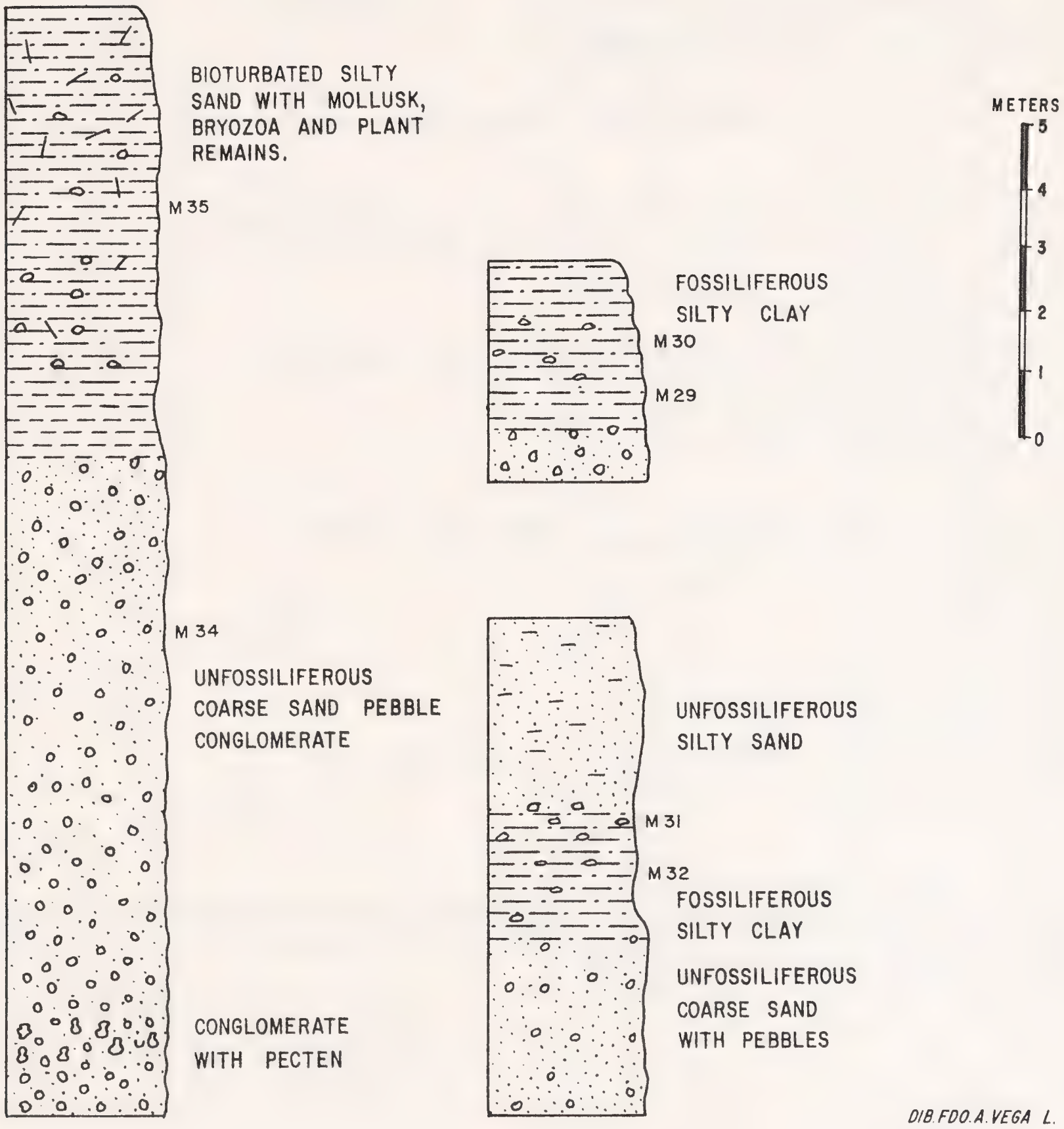

Figure 9. Stratigraphic section of the Agueguexquite strata in the eastern region, showing basal conglomerate (see Fig. 5 for map location).

niventra and *Pontocythere ashermani* (=*Hulingsina semicircularis*?) diagnostic of water depths less than 50 m. Puri and Vaanstrum (1969), indicated that "the occurrence of large total populations of *Puriana rugipunctata, Orionina vaughani* and *Aurila conradi* suggests stable environment conditions in shallow waters (less than 65 ft.)."

Cytherella vermilionensis has been reported by Kontrovitz (1976) in modern Louisiana inner neritic shelf sediments between 10 and 100 m, mostly between 10 and 50 m. *Cytherura sandbergi* has been reported by several authors from recent lagoonal and nearshore environments. *Cytherelloidea* sp. cf. *C. umbonata* was found by Teeter (1975) from a few centimeters to 10 m off the Belize's coast. *Bairdoppilata* sp. aff. *B. victrix* and *Cytherella* sp. aff. *C. pulchra* have been found by Bold in the Caribbean Pliocene shallow water sediments. Puri (1954) found that *Cativella navis, Cytheromorpha warneri, Cytheropteron (Microcytherura) choctawhatcheensis, Cytherelloidea leonensis, Loxoconcha wilberti*, and *Paracypris choctawhatcheensis*, among others, were characteristic of the Ecphora and Cancellaria facies of the Choctawhatchee Stage (inner-middle shelf). This fauna is very similar to the one in the Agueguexquite, therefore, the ostracofauna indicates that these beds were deposited in shallow, inner to possibly middle neritic environments.

Assemblages consisting of *Aurila* spp.,

Basslerites minutus, Cativella, Orionina, Puriana gatunensis, Quadracythere producta, and *Radimella confragosa,* occur concentrated in a belt from very near shore to a depth of about 20 m and generally paralleling the shoreline at a distance varying between 700 and 1200 m in the Gulf of Paria (Bold, 1974, Fig. 4). These conditions appear similar to the bathymetry of the Agueguexquite.

This interpretation agrees with the paleodepth suggested by the benthonic foraminifera found by Sansores and Flores-Covarrubias (1972), which represent an inner to middle neritic environment between 0 and 100 m.

The Bryozoa of these strata also confirm an inner neritic environment of deposition. Herrera-Anduaga (1983) found that autochthonous Bryozoa indicate a paleodepth of 0 to 55 m. Furthermore, she states that the bryozoans in the beds of the Pajaritos Dome along Highway 180 (locality B) are slightly deeper than those at locality A (see Figs. 5, 8B). This proposed difference in water depth for the two locations is supported by some differences in ostracode occurrence. *Basslerites minutus, Cytheretta choctawhatcheensis, Henryhowella* ex. gr. *asperrima,* and *Pterygocythereis inexpectata* do not occur at locality A (Fig. 8A) and their absence suggests slightly shallower conditions of deposition for these strata. As the ostracode bearing beds in locality A are stratigraphically above the ones along Highway 180, this further substantiates the shallowing-upward trend of the Basin.

CEDRAL (Castillo, 1955).

The Cedral "formation" consists of a series of yellowish-red and gray sand, shale and conglomerate with rare occurrences of the benthic foraminifera *Ammonia becarii* and *Elphidium* spp. It is considered to be of deltaic origin. No ostracodes were found in these beds.

V. CLUSTER ANALYSIS

In order to test the similarity among the samples taken from different formations, a Q-mode cluster analysis using Ward's method (SAS, 1982) and species proportions was performed. Species with over 2% in any sample and samples with over 100 specimens were used (of the Encanto and Lower Concepción samples, only one of each met this requirement).

Visual examination of the dendrogram in Fig. 7 reveals two major clusters each divided into two subclusters: (1) Cluster I comprises all of the Agueguexquite plus two Upper Concepción (TU 1030 and 1031) samples; (2) Cluster II consists of the Concepción samples.

The Agueguexquite samples are divided into two groups: (1) Subcluster Ia comprises all the samples from locality A, except the basal one (sample ANL). (2) Subcluster Ib is formed by ANL and the rest of the Agueguexquite samples.

The samples in subcluster Ib contain *Pterygocythereis inexpectata, Henryhowella* ex. gr. *asperrima, Cytheretta choctawhatcheensis,* and *Basslerites minutus.* These species are absent in the samples from locality A, and their presence indicates a slightly deeper environment.

The samples in locality B (Fig. 8B)(and probably the ones in the rest of the Agueguexquite localities), are stratigraphically below the ones in locality A; its deeper character agrees with the shallowing-upwards trend of the "formation."

Sample ANL is the lowest one in locality A (Fig. 8A) and it joins very early to samples L11 and M54 from locality B. These three samples contain abundant *Aurila* sp., *Malzella conradi, Radimella confragosa, Quadracythere compacta?, Orionina vaughani, Bairdoppilata* sp. aff. *B. victrix, Paracytheridea tschoppi,* and common *Cativella navis, Caudites nipeensis,* and *Echinocythereis* sp. It is possible that sample ANL represents the same conditions of deposition as samples L11 and M54, whereas the samples above them represent slightly shallower conditions.

The rest of the Agueguexquite samples (Fig. 9) seem to indicate a similar environment to the one in samples ANL, L11 and M54. Herrera-Anduaga (1983) found the same trend with Bryozoa. She reported a slightly shallower environment in the samples of locality A than for the ones in the rest of the localities.

Cluster II includes the Concepción samples. It is also divided into two groups: (1) Samples K66, K39, and M56, which joins later; (2) Samples 14, 15, K21 and K29.

The samples from subcluster IIb are all from the southern flank of the Sayula Dome (Fig. 3). They contain *Cyprideis* sp. cf. *C. mexicana, Loxoconcha matagordensis*, and *Haplocytheridea-Peratocytheridea* molts, which probably represent contamination from nearby shallow (or brackish) water environments.

Samples K66 and K39 were collected on the western flank of the Potrerillos Dome (Fig. 4). The presence of abundant *Echinocythereis* sp. and *Henryhowella* ex. gr. *asperrima*, and the absence of shallower cluster IIb species suggest that they represent a deeper environment. This agrees with the results obtained by Kohl (1985). He found that the benthic foraminifera of these samples indicate an outer neritic environment for the section in the western flank of the Potrerillos Dome, and an outer to middle neritic environment for the southern flank of the Sayula Dome.

Two of the Upper Concepción samples involved in the clustering procedure, TU 1030 and 1031 merge late with the Agueguexquite cluster. These samples are from outside the area of study and represent a shallower facies, as indicated by their high numbers of *Malzella conradi, Aurila* sp., *Orionina vaughani, Cytheropteron? yorktownensis*, and *Cytheretta choctawhatcheensis*. This assemblage may account for its merging (although late) with the Agueguexquite group. On the other hand, the absence of characteristic Concepción species such as *Hulingsina* sp. 1, *Actinocythereis vineyardensis, Buntonia* sp., *Cytherella* sp., *Megacythere repexa, Perissocytheridea* spp., and *Cyprideis* spp., accounts for its exclusion from that cluster. The lack of allochthonous brackish water species present in the other Concepción samples indicates that this contamination is locally restricted.

The Lower Concepción sample M56 remains independent joining late to cluster IIa, which contains the deepest water representatives of the samples analyzed (K39 represents a paleodepth close to upper bathyal).

The Encanto sample, K4, forms an independent entity, which joins very late to cluster 1. As mentioned before, this sample presents a mixed fauna of upper bathyal and inner shelf conditions, and since no other Encanto samples were used in the cluster (due to their low diversity and species abundance), its merging with the inner shelf Agueguexquite group seems logical.

VI. CONCLUSIONS

(1) The Pliocene strata in the Isthmian Salt Basin can be identified by their ostracode fauna.

(2) Each unit shows a characteristic assemblage:

(a) The Encanto beds can be recognized by the presence of *Ambocythere* spp., *Argilloecia posterotruncata, Bradleya normani, Krithe trinidadensis*, and *Parakrithe* spp. This fauna indicates a middle to upper bathyal environment and an age of Early to Middle Pliocene (upper N18 to N19).

(b) Concepción strata are distinguished by the presence of *Actinocythereis vineyardensis, Caudites rectangularis, Haplocytheridea-Peratocytheridea* molts, *Loxoconcha matagordensis*, and *Touroconcha lapidiscola*. Lower Concepción beds can be differentiated from Upper Concepción ones by the presence of *Ambocythere* spp. *Cytherella* sp. aff. *C. hannai* var., and *Parakrithe* spp. These species indicate upper bathyal to outer neritic environments and a Middle to Late Pliocene age (N19 - N20). Upper Concepción strata can be differentiated from Lower Concepción ones by the presence of *Malzella conradi, Echinocythereis margaritifera, Basslerites*? sp. and the abundance of brackish water species. This assemblage indicates outer to middle neritic environments and Late Pliocene (N20) age.

(c) Agueguexquite strata are characterized by abundant *Bairdia* and *Bairdoppilata* spp., *Cytherura* spp., *Cytherella vermilionensis, C.* sp. aff. *C. pulchra, Loxoconcha wilberti, Luvula gigarton*, and *Macrocyprina propinqua*. Their faunal assemblage indicates an inner neritic environment of deposition and a Late Pliocene (Middle N20) age.

(d) Samples from the Filisola, Paraje Solo, and Cedral strata did not contain ostracodes.

(3) The Pliocene depositional sequence of the Saline Basin shows a general shallowing-upward trend from middle to upper bathyal (Encanto) to upper bathyal – outer neritic (Lower Concepción), to outer - middle neritic (Upper Concepción) to nearshore and brackish conditions (Filisola + Paraje Solo). In the northern part of the Basin, a small transgression occurred and inner neritic marine sediments were deposited (Lower-Middle Agueguexquite) followed by the deposition of deltaic and continental deposits (Cedral).

(4) Clustering of the samples based on their specific content separated the Agueguexquite and Concepción strata.

VII. LOCALITY DATA

The samples used in this study came from a variety of sources, the abbreviations are:

K39, 40, 43, 49, 52, 63, 64, 66. Encanto and Concepción formations, Potrerillos Dome, coll. B. Kohl.

18, 19, 21, 22, Encanto and Concepción formations, Potrerillos Dome, coll. Machain and Bold.

K4, 21, 22, 29, Encanto and Concepción formations, Sayula Dome, coll. B. Kohl.

13, 14, 15, Upper Concepción Formation, Sayula Dome, coll. Machain and Bold.

AG21-25, Agueguexquite Formation, pipeline cut about 200 m north of Mexico Highway 180, km 13 (locality A), coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

ANL, Agueguexquite Formation, same locality as above, collected at the base of the sequence, coll. Bold.

M29-54, Agueguexquite and Concepción formations, series of outcrops along Mexico Highway 180 from Coatzacoalcos, Veracruz, to Agua Dulce, Veracruz, coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

M56-59, Lower Concepción Formation, hill at the El Chapo locality along the road from Nanchital to Las Choapas just after its crossing with the Southeastern Railroad, coll. Machain, Bold, Gío-Aráez and Herrera-Anduaga.

M60, Encanto Formation, Tuzandepetl Dome, coll. Machain, Bold, Gío-Argáez and Herrera-Anduaga.

M78, Encanto Formation, outcrop along México Highway 185, 14 km north of side road to Jesús Carranza.

Tulane University fossil locality numbers, coll. H. E. and E.H. Vokes.

638. Agueguexquite Formation, road cut, pipeline cut, and quarry on México Highway 180, 14 mi east of junction with side road into Coatzacoalcos, Veracruz.

1025. Lower Concepción Formation, first roadcut on east side of road between Nuevo Teapa and Ixhuatlán, 0.5 mi south of crossing of México Highway 180, Veracruz, México.

1030. Upper Concepción Formation, hill on left bank of Río Santo Domingo, just before its confluence with the Río Tonto, forming Río Papaloapan, just north of Tuxtepec, Oaxaca, México.

1031. Same locality as TU 1030 but about 7 m lower stratigraphically, river bank exposed at low water.

1046. Agueguexquite Formation, roadcuts on both sides of México Highway 180, 7.5 mi east of junction with side road into Coatzacoalcos, Veracruz, México.

1141. Filisola Formation, roadcut on north side of México Highway 180, 13 km west of San Andrés Tuxtla, Veracruz, México (= stop 10, 20th Geol. Congress, C-7, 1956).

1153. Encanto Formation, roadcut on México Highway 180, 16 km east of Acayucan, Veracruz, México.

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IX. APPENDIX – OSTRACODE SPECIES

1. *Actinocythereis gomillionensis* (Howe and Ellis, 1935)
2. *Actinocythereis* sp. cf. *A. gomillionensis* (Howe and Ellis, 1935)
3. *Actinocythereis vineyardensis* (Cushman, 1906)
4. *Ambocythere caudata* Bold, 1966
5. *Ambocythere* sp. cf. *A.* sp. A. Cronin, 1983
6. *Argilloecia posterotruncata* Bold, 1966
7. *Aurila* sp.
8. *Bairdia* sp. aff. *B. longisetosa* Brady, 1902
9. *Bairdoppilata* sp. aff. *B. victrix* (Brady, 1869)
10. *Bairdoppilata* sp.
11. *Basslerites minutus* Bold, 1958
12. *Basslerites*? sp.
13. *Bradleya normani* (Brady, 1865)
14. *Buntonia* sp.
15. *Cativella navis* Coryell and Fields, 1937
16. *Caudites nipeensis* Bold, 1946
17. *Caudites rectangularis* (Brady, 1869)
18. *Cushmanidea sagena* Benson and Kaesler, 1963
19. *Cyprideis salebrosa* Bold, 1963.
20. *Cyprideis* sp. cf. *C. mexicana* Sanberg, 1964
21. *Cytherella vermilionensis* Kontrovitz, 1976
22. *Cytherella* sp. aff. *C. hannai* Howe and Law, 1936

23. *Cytherella* sp. aff. *C. hannai* Howe and Law, 1936 var.
24. *Cytherella* sp. aff. *C. pulchra* Brady, 1866
25. *Cytherella* sp.
26. *Cytherelloidea leonensis* Howe, 1934
27. *Cytherelloidea umbonata* Edwards, 1944
28. *Cytherelloidea* sp. cf. *C. umbonata* Edwards, 1944
29. *Cytheretta anderseni* Butler, 1963
30. *Cytheretta bassleri* Howe, 1935
31. *Cytheretta choctawhatcheensis* Howe and Taylor, 1935
32. *Cytheromorpha warneri* Howe and Spurgeon, 1935
33. *Cytheropteron barkeri* Teeter, 1975
34. *Cytheropteron morgani* Kontrovitz, 1976
35. *Cytheropteron* sp. aff. *C. hamatum* Kontrovitz, 1976
36. *Cytheropteron? yorktownensis* (Malkin, 1953)
37. *Cytherura sandbergi* Morales, 1966
38. *Cytherura wardensis* Howe and Brown, 1935
39. *Cytherura* sp. A
40. *Echinocythereis margaritifera* (Brady, 1870)
41. *Echinocythereis* sp.
42. *Euctythere* sp. aff. *E. triangulata* Puri, 1954 of Howe and Bold, 1975
43. *Eucytherura* sp. 1 Howe and Bold, 1975
44. *Eucytherura* sp. 2 Howe and Bold, 1975
45. *Gangamocytheridea? plicata* Bold, 1968
46. *Haplocytheridea-Peratocytheridea* molts.
47. *Hemicytherid* molts.
48. *Henryhowella* ex. gr. *asperrima* (Reuss, 1849)
49. *Hulingsina semicircularis* (Ulrich and Bassler, 1904)
50. *Hulingsina* sp. 1.
51. *Hulingsina* sp. 2.
52. *Hulingsina* sp. 3.
53. *Kangarina ancyla* Bold, 1963
54. *Krithe trinidadensis* Bold, 1958
55. *Loxoconcha matagordensis* Swain, 1955
56. *Loxoconcha wilberti* Puri, 1954
57. *Loxoconcha* sp. aff. *L. helenae* Crouch, 1949
58. *Loxoconcha* sp. A Hazel, 1977
59. *Loxocorniculum tricornatum* Krutak, 1971
60. *Luvula gigarton* Bold, 1966
61. *Macrocyprina propinqua* Triebel, 1960
62. *Malzella conradi* (Howe and McGuirt, 1935)
63. *Megacythere repexa* Garbett and Maddocks, 1979)
64. *Microcytherura choctawhatheensis* (Puri, 1954)
65. *Munseyella bermudezi louisianensis* Kontrovitz, 1976
66. *Mutilus*? sp.
67. *Neocaudites scottae* Teeter, 1975
68. *Orionina vaughani* (Ulrich and Bassler, 1904)
69. *Paracypris* sp. cf. *P. choctawhatcheensis* Puri, 1954
70. *Paracypris* sp. cf. *P. franquesi* Howe and Chambers, 1935
71. *Paracytheridea tschoppi* Bold, 1946
72. *Paracytheridea* sp.
73. *Parakrithe* sp. 1.
74. *Parakrithe* sp. 2.
75. *Pellucistoma magniventra* Edwards, 1944
76. *Perissocytheridea bicelliforma* Swain, 1955
77. *Perissocytheridea subrugosa* (Brady, 1870)
78. *Pseudopsammocythere vicksburgensis* Howe and Law, 1936
79. *Pterygocythereis alophia* Hazel, 1983
80. *Pterygocythereis inexpectata* (Blake, 1929)
81. *Pterygocythereis* sp. 1.
82. *Puriana rugipunctata gatunensis* (Coryell and Fields, 1937)
83. *Puriana* sp. 1
84. *Puriana* molts.
85. *Quadracythere compacta* (Brady?) Bold, 1975.
86. *Radimella confragosa* (Edwards, 1944)
87. *Thalassocypria*? sp.
88. *Touroconcha lapidiscola* (Hartmann, 1959)
89. *Xestoleberis* sp. 1
90. *Xestoleberis* sp. 2

December 15, 1986

REVIEW

STORM DEPOSITIONAL SYSTEMS, by Thomas Aigner. Lecture Notes in Earth Sciences, 3: Published by Springer-Verlag, Berlin, Heidelberg, New York, and Tokyo, 1985, viii + 174 pp., illus., paper, $14.50

In this volume, the geological effects of storms and hurricanes are investigated and their role as tools in facies and paleogeographical analysis is explored. In part one, case studies of modern carbonate and terrigenous clastic storm sedimentation are presented. Models are derived which can be used in the interpretation of ancient analogues. Part two is an analysis of an ancient storm depositional system (the Muschelkalk) on a basin-wide scale.

–HCS

VIGNETTES OF COASTAL PLAIN GEOLOGY

GILBERT DENNISON HARRIS

(1864-1952)

This photograph is said to be "Harris during his Louisiana years" (Rebecca Harris, *in litt.)* As Harris was in charge of the Louisiana State Geological Survey from 1898 to 1909, we assume the picture dates from those years. But who are the other two gentlemen flanking him? His principal assistant during this time was Arthur Veatch, who was 14 years Harris's junior so neither is likely to be Veatch. One of the significant effects of their mapping of Louisiana was the recognition of the Sabine Uplift in the northwestern part of the state.

FRESH AND BRACKISH WATER OSTRACODA FROM THE NEOGENE OF NORTHERN VENEZUELA

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I. ABSTRACT

Twenty-four species of ostracodes are recorded from the Siquire, Tuy and Cumaca formations of the State of Miranda and from the Guiria Formation of the State of Sucre. Three new species are described: *Cytheridea? purperae*, *Callistocythere? macsotayi* and *Xestoleberis bermudezi*. The lower Siquire Formation is correlated with the lowermost unit (Unit J) of the Guiria Formation and with the Caparo clay member of the Talparo Formation of Trinidad (Pliocene). The upper Siquire Formation is correlated with the upper Talparo Formation, and the Tuy Formation and Unit E of the Guiria Formation are tentatively assigned to the Pleistocene.

RESUMEN

En las formaciones Siquire, Tuy y Cumaca del Estado de Miranda y en la formación Guiria del Estado Sucre se registran veinticuatro especies de ostrácodos. Aquí se describen tres especies nuevas: *Cytheridea? purperae*, *Callistocythere? macsotayi* y *Xestoleberis bermudezi*. La parte inferior de la formación Siquire se correlaciona con la parte inferior (Unidad J) de la Formacion Guiria y con el miembro argilloso Caparo de la formacioń Talparo de Trinidad (Plioceno). La parte superior de la formación Siquire se correlaciona con la parte superior de la formación Talparo; la formación Tuy y la Unidad E de la formación Guiria superior se ponen con reserva en el Pleistoceno.

II. INTRODUCTION

One of the frustrating problems for a paleontologist is the dating of Cenozoic fresh or brackish water deposits. They often contain only endemic, and specialized, environmentally controlled faunas. They are usually not overlain by datable younger sediments and often overlie much older deposits unconformably. Within the Caribbean Region there are several examples, including in Venezuela, the Siquire, Cumaca and Tuy Formations of Miranda (Picard and Pimentel, 1968), and the Guiria Formation of Sucre (Macsotay, 1976); and in Hispaniola, the Jimaní Formation of the Hoya de Enriquillo and its equivalents in the Cul-de-Sac continuation (Bold, 1975). In Brasil, Ivone Purper (1977, 1979) encountered a similar situation with the Pebas Formation of the upper Amazon basin, as did Sheppard and Bate (1980) in

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Colombia and Peru. In Colombia I have found the dating of the so-called "*Chara*-zone" in the upper Magdalena Valley of the department of Huila equally difficult.

Additional problems may occur when foraminifer and ostracode-rich unconsolidated sediments are reworked into lacustrine environment, where the fauna consists of very thin-shelled and fragile species, which are destroyed in sample preparation. I recently encountered this in the Neogene of the Camp Perrin Basin of southern Haiti, where the fresh water ostsracodes disintegrate completely on washing so that the residue contains only well preserved (but reworked) marine forms. A similar situation is present in the Llanos region of Ecuador where Cretaceous planktonic foraminifera have been redeposited in Tertiary fresh and brackish water sediments (Tschopp, 1953). The result of all this is that specialists on different groups of fossils will inevitably come to totally different conclusions about the age and environment of such sediments.

The purpose of this paper is to discuss the biostratigraphic distribution of the ostracodes of the Siquire, Cumaca, Tuy and Guiria formations and their relations to faunas from Trinidad and Hispaniola. The results of the study are at variance with previous paleontological interpretations.

III. ACKNOWLEDGMENTS

I am indebted to Christian Beck (University of Lille, France) and Oliver Macsotay (Universidad de Oriente, Cumaná, Venezuela) for providing the samples on which this study is based. I dedicate this paper to the late Pedro Bermúdez, who also contributed material. I wish to thank R. M. Forester for the numerous notations made in reviewing the manuscript; I have followed many of his suggestions.

IV. MATERIAL STUDIED

BASIN OF SANTA LUCIA - OCUMARE DEL TUY

In this basin (Estado Miranda) two formations are present, which have yielded a small number of fresh and brackish water ostracodes. The Siquire Formation unconformably overlies metamorphic rocks and underlies the Tuy Formation with local unconformity (Picard and Pimentel, 1968). Dr. C. Beck (University of Lille, France) sent me samples of the Siquire Formation, which were taken along a section about 2 km long, running from about 1 km south of Sta. Teresa to the north-northwest (Text-Fig. 1). From the late Dr. P. J. Bermúdez I received a sample from the Tuy Formation (Picard and Pimentel, 1968, p. 284). Dr. Bermúdez also furnished a sample of the Cumaca Formation, which is the supposed equivalent of the Siquire Formation in the Lower Tuy-Barlovento basin (Picard and Pimentel, 1968).

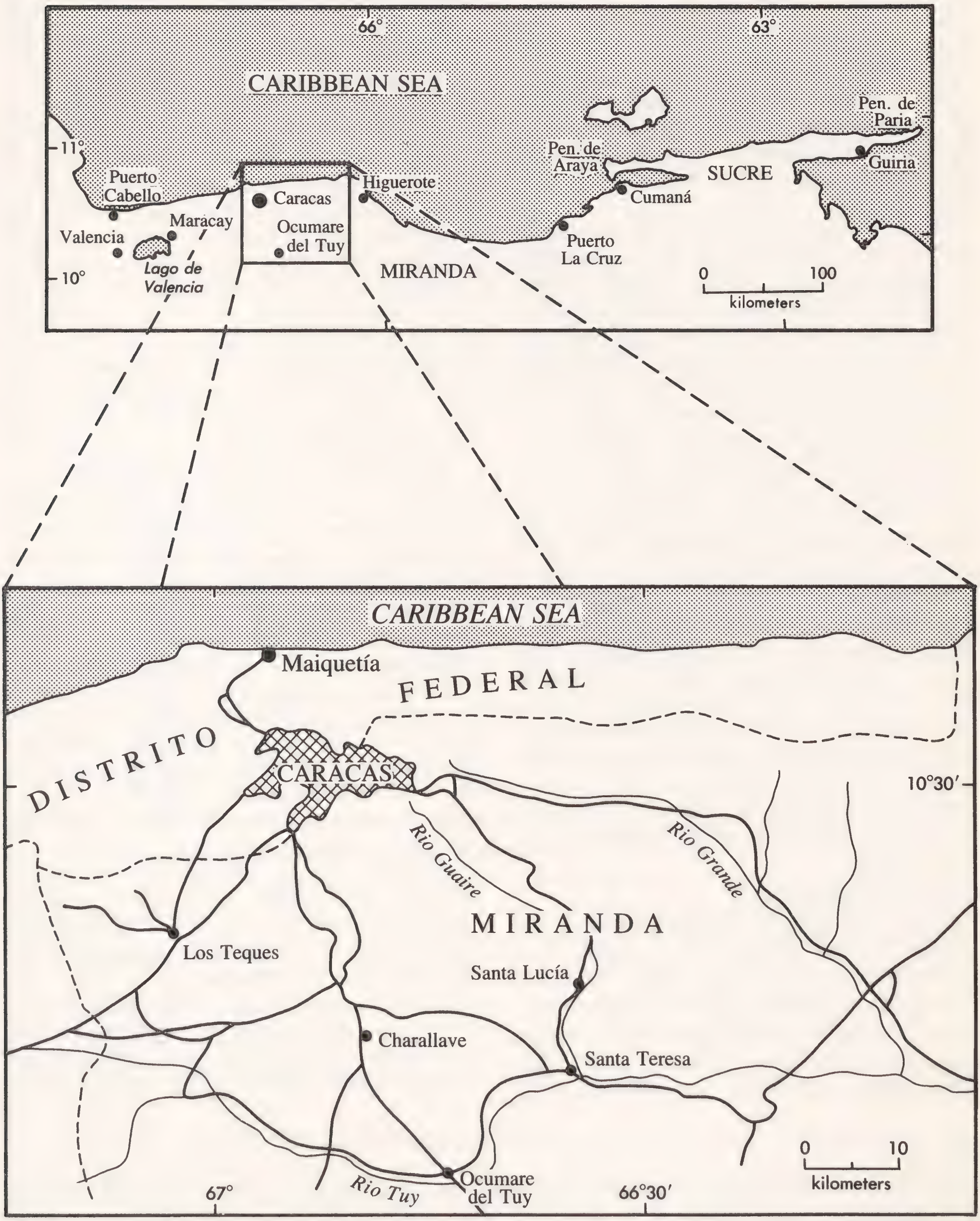
In the Siquire Formation (Table 1) the most common ostracodes are species of *Darwinula* and *Limnocythere*, usually characteristic of ephemeral or permanent lakes. Many of the freshwater ostracodes are represented only by casts with occasionally adherent parts of shell material; thus, generic determinations are somewhat uncertain and specific determinations unreliable. Only two samples show a more diverse fauna which, in addition to fresh water forms, also contains some (probably) brackish water Cytheracea. It is especially in these samples that shell material is slightly thicker and, therefore, partly or even completely preserved.

In the lower part of the Siquire Formation (Samples 858-886) the fauna is dominated by *Limnocythere* sp. 1 and 3. Sample 885 yielded *Darwinula* sp. aff. *D. olivencae* Purper, *Pseudocandona*? sp. and *Limnocythere* sp. 3, as well as *Cytheridea? rohri* (Bold, 1963), which is known from the Talparo Formation of Trinidad and the Guiria Formation of the Paria peninsula (Bold *in* Macsotay, 1968, p. 64; Bold, 1972, Table 2).

The upper part of the Siquire Formation (samples 890-952) is characterized by *Limnocythere* sp. 2. Sample 898 contains, in addition to *Stenocypris?* sp. and *Heterocypris?* sp., also *Cytheridella boldi* Purper, *Cytheridea? rohri* (Bold) and *Cytheridea? purperae* n. sp. Conspicuous in this sample is the absence of *Darwinula* and *Limnocythere*, which suggests an interruption of lacustrine deposition by a brackish water invasion. *Cytheridella boldi* is living in Lago de Valencia (Text-fig. 1), and has been found as a fossil in the Jimaní Formation of Hispaniola (Bold, 1975) and in the upper part of the Talparo Formation of

Trinidad (M. Dempsey, Texaco Trinidad, letter and material, 1972.

Bermúdez' sample (VB-2) from the Cumaca Formation (Bold, 1972, p. 1012) only contains *Limnocythere staplini* Gutentag and Benson (1962), originally described from the Pleistocene of Kansas and subsequently reported from the upper Las Salinas Formation and the Jimaní Formation of Hispaniola (Bold, 1975), late



Text-fig. 1. Map of the study area.

Pliocene or Pleistocene in age. In North America this species is found in lakes in which the water is enriched in Na, Mg, Ca, SO2, and Cl, and depleted in HCO_3 (Forester, 1983), which suggests that similar conditions may have been present in the Cumaca lake(s).

The Bermúdez sample from the Tuy Formation (VB-1, Bermúdez, 1966, p. 344; Bold, 1972, p. 1012) contains *Darwinula* sp. aff. *D. olivencae* Purper, *Pseudocandona?* sp., Ostracode sp., *Limnocythere* sp. 4, and *Cytheridea? purpera* n. sp., the latter also occurring in the Siquire and Guiria Formations.

The fauna of the lower "brackish water" intercalation of the Siquire Formation (885) correlates well with the brackish-marine lower part of the Guiria Formation (Unit J of Macsotay, 1968, p. 55) and the brackish water parts of the Talparo Formation (Table 1). The upper "brackish water" intercalation (898) is somewhat similar in fauna to the upper part of the Guiria Formation (Unit E of Macsotay, 1968, p. 56), which lacks, however, *Cytheridea rohri*, and to the fresh water upper part of the Talparo Formation. According to this evidence the Siquire Formation should be of late Pliocene age. This is in complete disagreement with other investigators, who assigned it an early to middle Miocene age (Picard and Pimentel, 1968; Macsotay, 1968). The Tuy Formation (also without *Cytheridea rohri*) could be contemporaneous with the upper part of the Guiria Formation and of late Pliocene to early Pleistocene age. This is still much younger than Macsotay's conclusion of a late Miocene to Pliocene age.

PARIA PENINSULA

From the Guiria Formation (State of Sucre) I have only two samples that yielded ostracodes. One (496a), collected by Bermúdez from the base of Macsotay's Unit J, 4-5 m above the base of the formation (Macsotay, 1968, p. 56), contains *Cyprideis similis* (Brady), *Cytheridea? rohri* (Bold), *Perissocytheridea subrugosa* (Brady), *P. cytheridellaformis* Forester, *Cativella pulleyi* Teeter, *Basslerites minutus* Bold, *Loxoconcha levis* Brady, *Callistocythere? macsotayi* n. sp., and *Xestoleberis bermudezi* n. sp. The *Cativella* and *Basslerites* species are marine forms with a fairly long stratigraphic range in the Neogene. *Cytheridea? rohri* occurs in the Caparo and Chin-Chin clay members of the Talparo Formation. *Perissocytheridea subrugosa* is known from Pliocene to Recent in the Greater Antilles and Trinidad, whereas the other brackish water species *P. cytheridellaformis* has been found so far only in the upper Las Salinas Formation of Hispaniola (*Cyprideis salebrosa* zone, late Pliocene - Recent). *Cyprideis similis* has the same range as *C. salebrosa*. *Loxoconcha levis* is known from Pliocene to Recent brackish water deposits in the Caribbean; it occurs throughout the Talparo Formation, except the Sum-Sum sand member (Table 1).

In the Caribbean the brackish water Pliocene can be subdivided into a late and early division on the basis of the presence or absence of *Cyprideis salebrosa* and *C. similis*. The boundary should lie close to that of the zones N 18 and N 19 of the planktonic foraminiferal zonation (Bold, 1983). In this scheme the upper Las Salinas Formation and most of the Talparo Formation, as well as the lower part of the Guiria Formation belong to the late Pliocene. Macsotay (1968), in contrast, places all of the Guiria Formation in the Pleistocene. The regional and local brackish water ostracode zonation of the Pliocene of Trinidad is shown in Text-fig. 2, which is based on Bold (1963), with additions by M. Dempsey (Texaco Trinidad, Company report, 1972). Here also the position of the *C.? rohri* zone is indicated.

The other sample was collected by Macsotay from his Unit E (42-45 m above the base of the Guiria Formation) and contains a fresh water fauna (except for the inclu-

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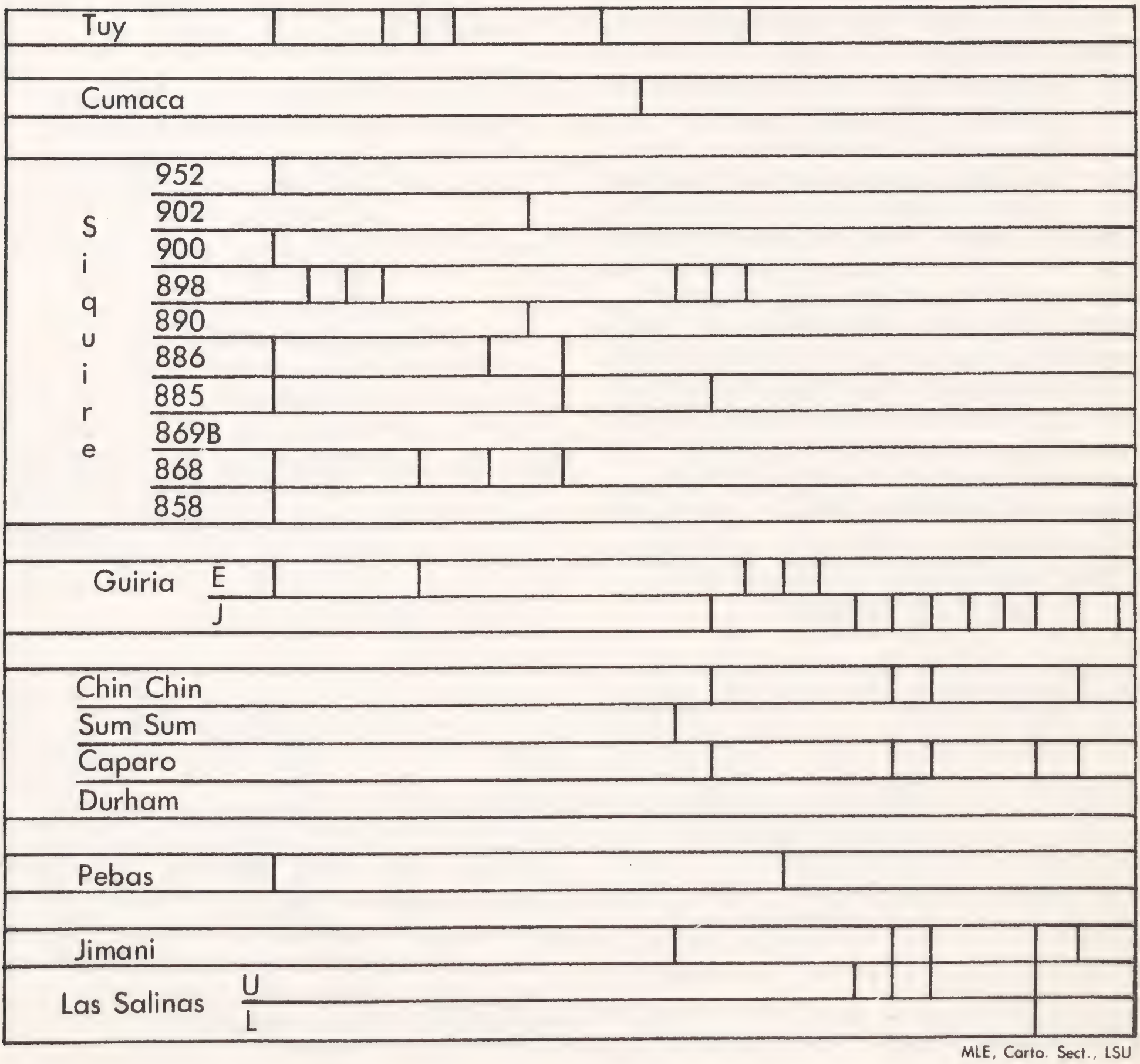
Table 1: Distribution of Ostracoda in northeastern Venezuela (Tuy, Cumaca, Siquire and Guiria formations), northern Trinidad (Chin Chin, Sum Sum, Caparoi and Durham members of the Talparo Formatiuons), the upper Amazon basin (Pebas Formation) and the Enriquillo basin in Hispaniola (Jimaní and Las Salinas formations). >

Darwinula sp. aff. *D. fragilis* Purper
Ilyocypris sp.
Stenocypris? sp.
Heterocyrpris? sp.
Candona sp. 1
Ostracode sp.
Limnocythere sp. 1
Limnocythere sp. 2
Limnocythere sp. 3
Limnocythere sp. 4
Limnocythere staplini Gutentag and Benson
Cytheridella boldi Purper
Cytheridea rohri (Bold)
Cytheridea purperae n. sp.
Cyprıa aequalica Sheppard and Bate
Potamocypris sp.
Perissocytheridea cytheridellaformis Forester
Perissocytheridea subrugosa (Brady)
Cyprideis similis (Brady)
Callistocythere? macsotayi n. sp.
Cativella pulleyi Teeter
Basslerites minutus Bold
Loxoconcha levis Brady
Xestoleberis bermudezi n. sp.



MLE, Carto. Sect., LSU

sion of *Cytheridea purperae* n. sp.) *Darwinula* sp. aff. *D. olivencae* Purper, *Potamocypris* sp., *Cypria aequalica* Sheppard and Bate, and *Heterocypris?* sp. *Cypria aequalica* (= *Cypria?* sp. 2, Purper, 1979) was described from the Pebas Formation of the upper Amazon basin. Tentative age assignments of the Pebas Formation generally agree on a late Pliocene to Pleistocene age, (Purper, 1979, Sheppard and Bate, 1980). *Cytheridea? purperae* is known from the Siquire and Tuy Formation and is probably closely related to species from the upper Amazon basin (see Systematic Descriptions).

V. DISCUSSION

The position of the *Cytheridea? rohri* zone in Trinidad (Text-fig. 2) in the late Pliocene puts some restrictions on the stratigraphic position of Unit J of the Guiria Formation and the whole of the Siquire Formation. The fact that *C? rohri* and *C? purperae* occur together in the Upper Siquire Formation may indicate that this part of the formation is slightly older than Unit E of the Guiria Formation, where only the latter species is found. Unit E may be more or less contemporaneous with the Tuy Formation. However, we know very little about environmental preferences of *C? purperae* and its upper Amazon relatives. It may conceivably have lived in an almost pure fresh water environment and thereby have been a tropical equivalent of the boreal form *Cytherissa lacustris* (Sars). Such forms have not been found in Recent tropical pools and lakes, but they may have enjoyed a brief period of development during the late Neogene time of climatic deterioration.

Therefore, it is quite possible that *C? rohri* is eliminated in low salinities that were tolerated by *C? purperae* in the upper part of the Guiria Formation, whereas in the Talparo Formation salinity may have been excessive for *C? purperae*. However, if we assume that the two species are indicative of more or less the same degree of salinity (after all, they do occur together in the same sample) and that, therefore, their presence or absence is stratigraphically significant, a tentative correlation between the Northern basin of Trinidad, the Paria Peninsula and the Sta. Lucia-Ocumare del Tuy basin, as shown in Text-fig. 3, would appear plausible.

VI. SYSTEMATIC DESCRIPTIONS

Types and illustrated specimens have been deposited in the H. V. Howe collections, Louisiana State University, Baton Rouge: HVH nos. 10750-10789.

Subclass OSTRACODA Latreille, 1806
Order PODOCOPIDA Müller, 1894
Suborder PODOCOPINA Sars, 1866
Superfamily DARWINULACEA Brady and Norman, 1889
Family DARWINULIDAE Brady and Norman, 1889
Genus DARWINULA
Brady and Robertson, 1885

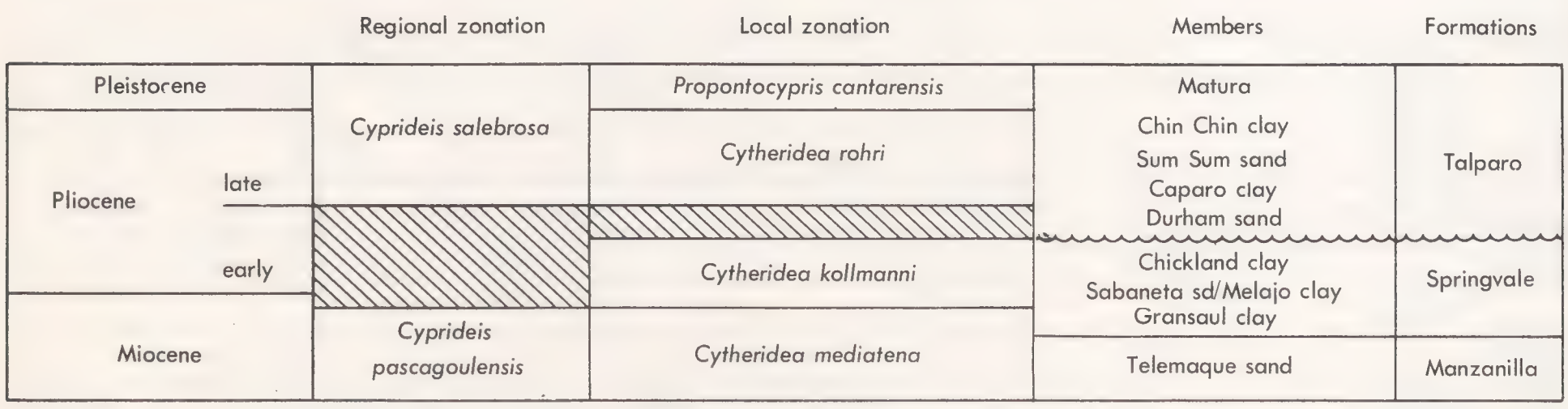
DARWINULA sp. aff. D. OLIVENCAE Purper

Plate 1, fig. 1

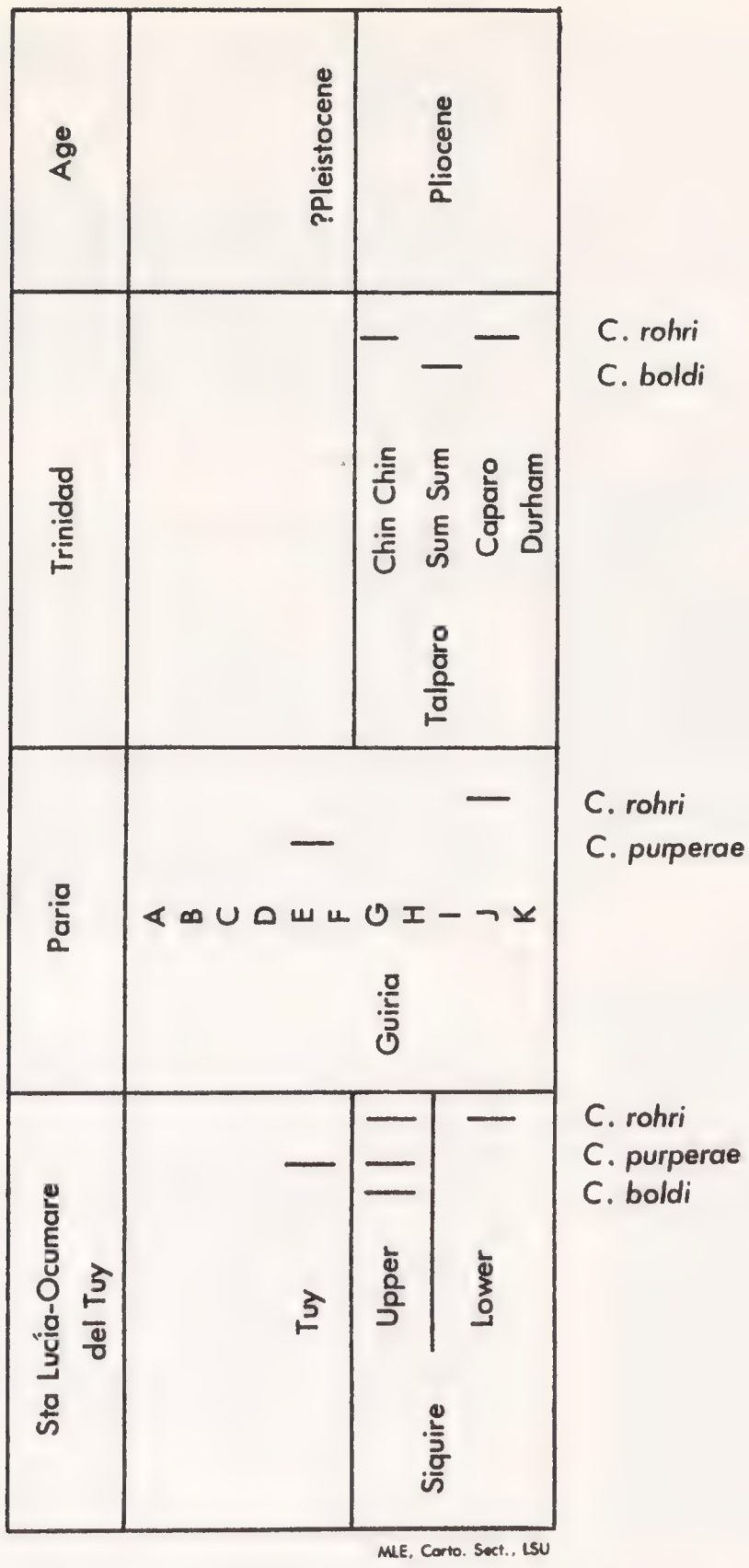
Darwinula sp. PURPER, 1977, p. 364, pl. 4, figs. 5-8.

Darwinula fragilis PURPER, 1979, p. 225, pl. 1, figs. 4-10 (*not* Schneider, 1948).

Darwinula sp. SHEPPARD and BATE, 1980, p. 117, pl. 13, fig.a 7.



Text-fig. 2. Regional and local ostracode zonation, Formations and Members of the Upper Miocene to Pleistocene in the Northern Basin of Trinidad.



Text-fig. 3. Correlation of Plio-Pleistocene formations of the Sta. Lucia-Ocumare del Tuy basin, the Paria Peninsula and the Northern Basin of Trinidad. Presence of *Cytheridea? rohri*, *Cytheridea? purperae* and *Cytheridella boldi* is indicated.

Darwinula olivencae PURPER, 1984, p. 1371.

Dimensions: Female Left valve: L 0.54 mm, H 0.23 mm; right valve: L 0.53 mm, H 0.24 mm. Male right valve: L 0.55 mm, H 0.24 mm.

Distribution: Tuy, Siquire, and upper Guiria formations.

Remarks: The specimens are identical in outline to *Darwinula* sp. from the Pebas Formation of Peru, but very slightly larger. They are a bit less slender than Purper's species from the Pebas Formation of Brazil, but appear to have the same outline. In view of the great similarity between all *Darwinula* species, its identity cannot be proven.

Superfamily CYPRIDACEA Baird, 1846
Family CYCLOCYPRIDIDAE
Kaufmann, 1900
Genus CYPRIA Zenker, 1864
CYPRIA AEQUALIS Sheppard and Bate
Plate 1, fig. 3

Cypria aequalis SHEPPARD and BATE, 1979, p. 116, pl. 13, figs. 1-6.

Cypria? sp. 2 PURPER, 1980, p. 247, pl. 8, figs. 17-18.

Dimensions: L 0.39 mm, H 0.28 mm.

Remarks: Forester, in reviewing this paper, suggested that this species might rather belong to *Physocypria* Vavra, 1898. Only juvenile specimens have been found in the upper part of the Guiria Formation. They have the same outline and length/height ratio as Sheppard and Bate's specimens from Peru and Colombia and those of the Pebas Formation of Brazil. Adults have been found in the "*Chara* zone" of Huila, Colombia.

Family CANDONIDAE Kaufmann, 1900
Genus PSEUDOCANDONA
Kaufmann, 1900
PSEUDOCANDONA? sp.

Dimensions: L 0.90 ;mm, H 0.46 mm.

Distribution: Tuy, lower Siquire, and upper Guiria formations.

Remarks: This species is similar in outline to *P. antilleana* Broodbakker (1983, p. 296, fig. 4A-K, 5A-J) but slightly larger. As all recovered specimens were casts no further identification is attempted.

Family CYPRIDIDAE Baird, 1845
Subfamily CYPRINOTINAE Bronstein, 1947
Genus HETEROCYPRIS Claus, 1893
HETEROCYPRIS? sp
Plate 1, fig. 5

Description: Carapace in side view elongate bean-shaped, highest just behind the middle. Anterior margin almost evenly rounded; dorsal margin slightly angled at the greatest height, gently convex on both sides of it; ventral margin almost straight, very slightly concave just behind the middle; posterior margin slightly obliquely rounded; posterior end slightly lower than anterior. Dorsal view pod-shaped; posterior end slightly wider than anterior, greatest width in the middle.

Dimensions: L 0.75 mm; H 0.35 mm; W 0.30 mm.

Distribution: Upper Siquire and Tuy formations.

Subfamily HERPETOCYPRIDIDAE Kaufmann, 1900

Genus STENOCYPRIS Sara, 1899

STENOCYPRIS? sp.
Plate 1, fig. 2

Description: Carapace in side view elongate, highest at 3/8 of the length from the anterior extremity. Anterior margin evenly rounded in lower 2/3 with long, straight dorsal slope; dorsal margin straight, converging posteriorly towards the sinuate ventral margin; posterior margin narrowly rounded subventrally, obliquely truncate above. Dorsal view pod-shaped, widest in the middle, ends acuminate.

Dimensions: L 1.18 mm, H 0.53 mm, W 0.38 mm. The larger specimens are accompanied by internal casts of smaller dimensions of about the same shape, probably juveniles: L 0.88 mm, H 0.40 mm; L 0.74 mm, H 0.34 mm. It is uncertain if the larger specimens are adults.

Distribution: Upper Siquire Formation.

Remarks: As the marginal area could not be studied in the present material, the assignment to *Stenocypris* is based on external morphology only. *Stenocypris major* (Baird) (see Triebel, 1953, pl. 1, fig. 1-6; pl. 2, fig. 7-14) is larger, has parallel dorsal and ventral margins and a less steeply truncate posterodorsal margin.

Family CYPRIDOPSIDAE Kaufmann, 1900

Genus POTAMOCYPRIS Brady, 1870

POTAMOCYPRIS sp.
Plate 1, fig. 6

Description: Carapace triangular in side view, highest at about 1/3 of the length from the anterior extremity. Anterior margin obliquely rounded; dorsal margin gently convex, sloping down from the greatest height and continuing into the more steeply sloping posterior margin, which is narrowly rounded ventrally; ventral margin sinuate.

Dimensions: L 0.55 mm, H 0.29 mm.

Distribution: Upper Guiria Formation (Unit E).

Remarks: This form shows similarity with *P. schubarti* Klie (1940, p. 65, figs. 11-19) from northeastern Brasil, but has the greatest height more anteriorly located. It is ventrally less concave and posterodorsally less angulate than *P.* sp. aff. *P. schubarti* (Bold, 1976, table 9) from Lago de Valencia, Recent, Venezuela.

Family ILYOCYPRIDIDAE Kaufmann, 1900

Genus ILYOCYPRIS Brady and Norman, 1889

ILYOCYPRIS sp.
Plate 1, fig. 4

Description: Carapace large, subelliptical to rectangular. Anterior end evenly rounded, dorsal and ventral margin almost straight and parallel, posterior end slightly obliquely rounded. Surface finely pitted. Two sulci extend from the

---

PLATE 1

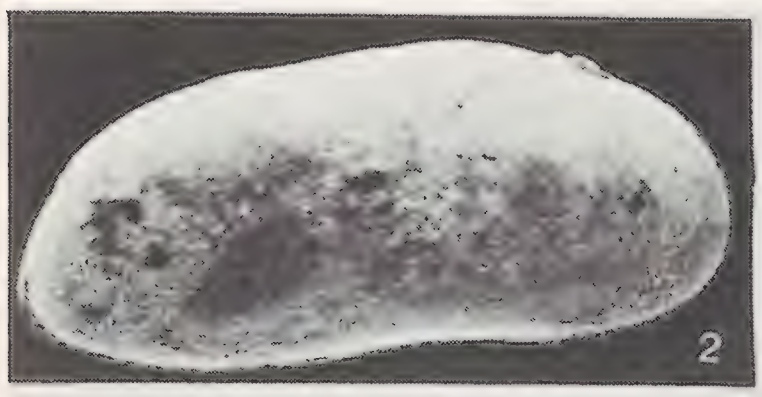
Figures

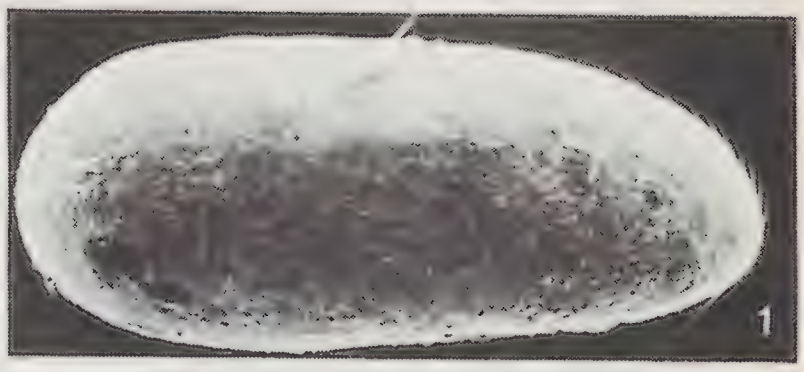
1. *Darwinula* sp. aff. *D. fragilis* Purper, HVH 10780, right valve view. loc. CB 77-885. Siquire Formation. 90 x.
2. *Stenocypris*? sp., HVH 10782, right valve view, loc. CB 77-898, Siquire Formation. 40 X.
3. *Cypria aequalica* Sheppard and Bate, HVH 10781, right valve, Unit E, Guiria Formation. 90 X.
4. *Ilyocypris* sp., HVH 10785, left valve view, loc. CB 77-898, Siquire Formation. 30 X.
5. *Heterocypris* sp., HVH 10784, right valve view, loc. CB 77-898, Siqurie Formation. 60 X.
6. *Potamocypris* sp., HVH 10783, right valve view, Unit E, Guiria Formation. 150 X.

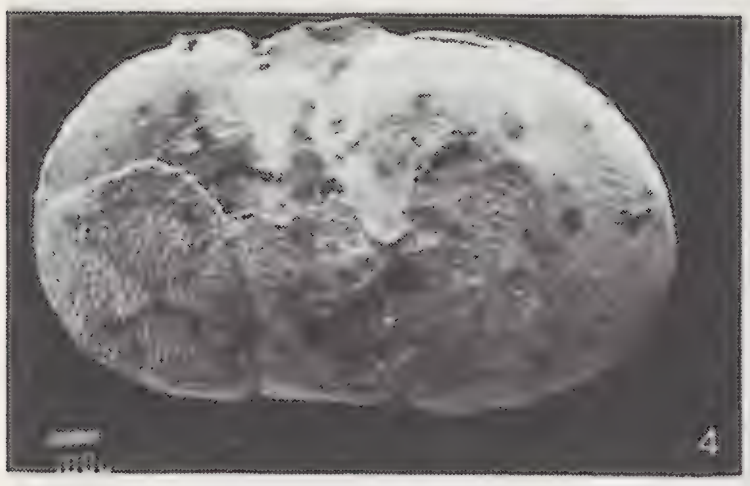
7-11. *Cytheridea purperae* n. sp., loc. VB-1, Tuy Formation. 50X. 7, HVH 10755, holotype, right valve, female; 8, HVH 10756, left valve, female; 9, HVH 10757, dorsal view, female; HVH 10758, left valve, male; 11, HVH 10759, right valve, male.

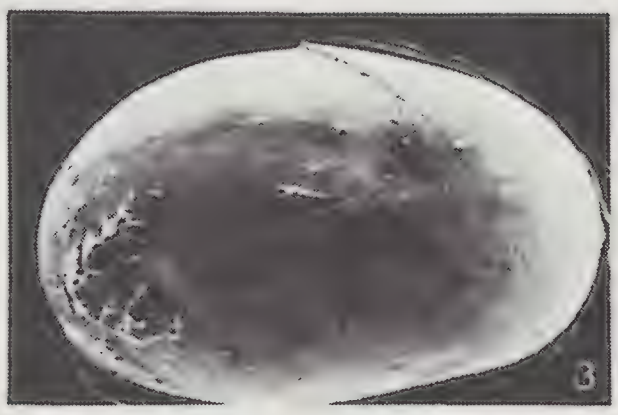
12. *Pacambocythere campana* (Sheppard and Bate), HVH 10771, right valve view, female, loc. Ka 116b "*Chara* Zone," Huila, Colombia. 85 X.

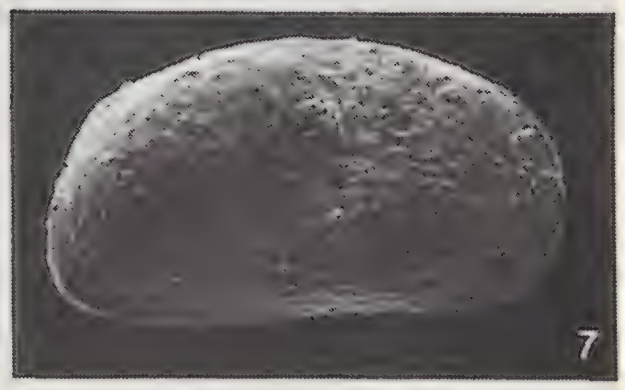
13-14. *Perissocytheridea subrugosa* (Brady), HVH 10770, Unit J. Guiria Formation. 85 X. 13, Dorsal view, female; 14, dorsal view, male.

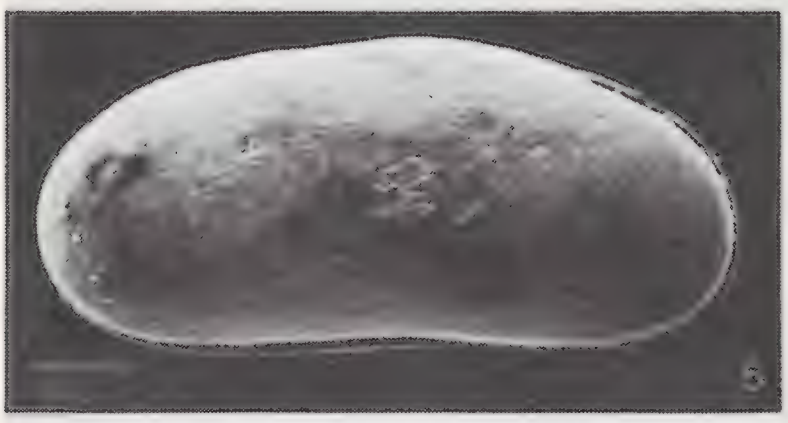


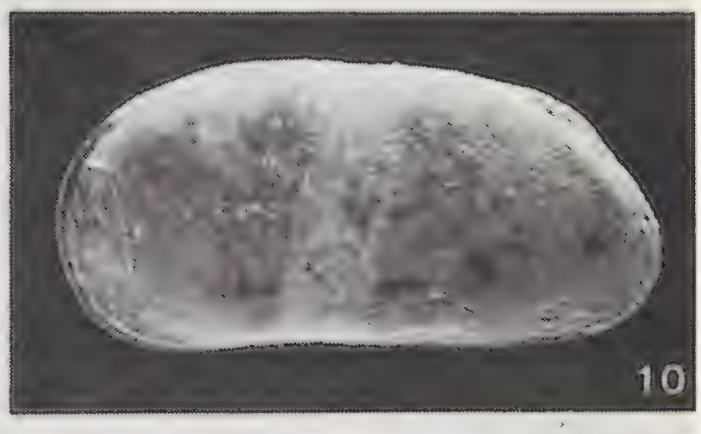


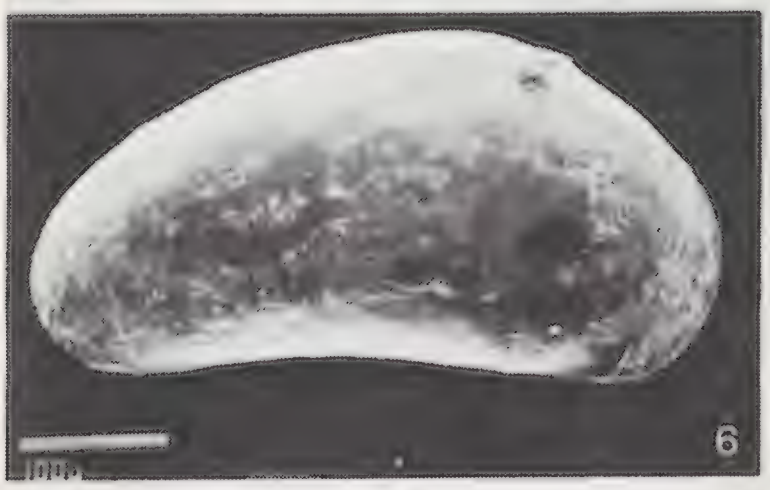


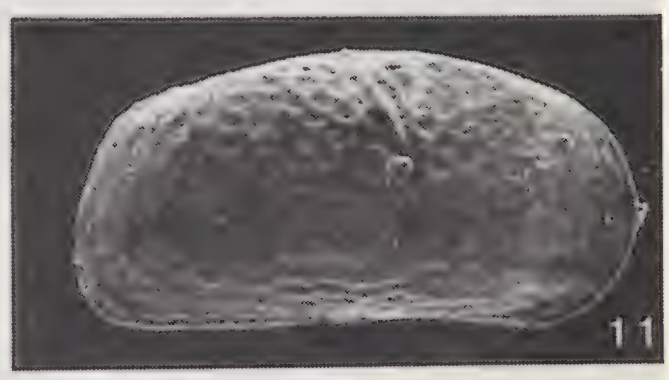


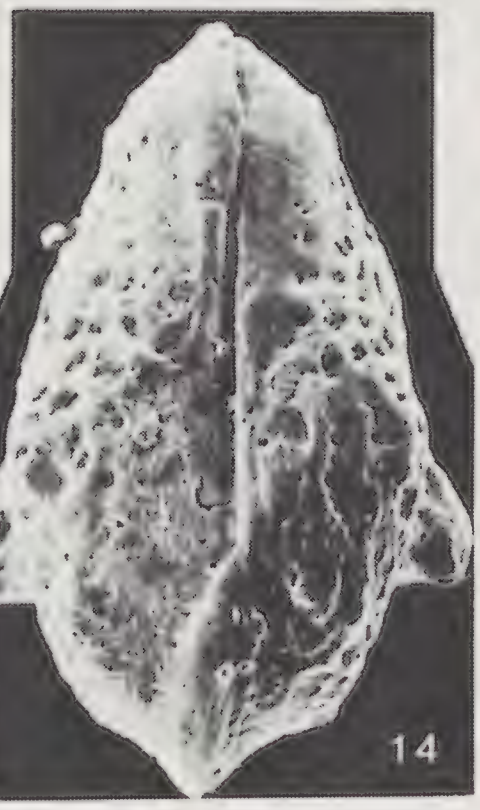












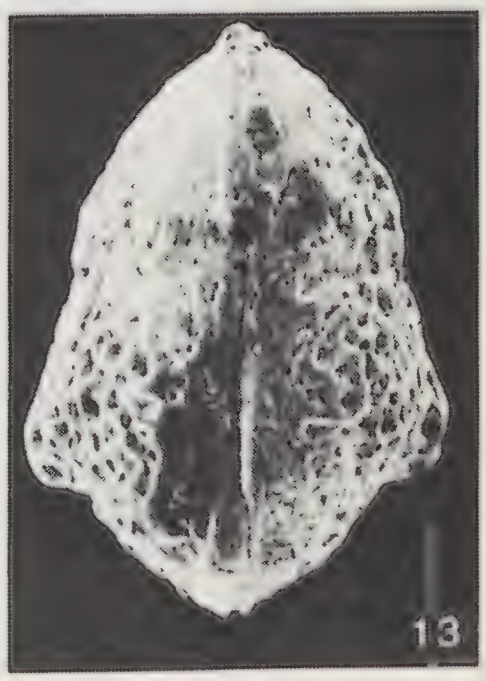


PLATE 1

dorsal margin slightly obliquely downward and backward to just above median height, one at 2/5 of the length from the anterior extremity, the other centrally located. Adductor muscle scars situated below and slightly in front of the central sulcus. Left valve slightly overlapping the right along dorsal margin, right valve slightly overlapping in the posterior end. Dorsal view lanceolate, widest at about 1/4 of the length from the posterior extremity.

Dimensions: L 1.35 mm, H 0.78 mm, W 0.55 mm.

Distribution: Only sample 898, Siquire Formation (common, but all specimens damaged).

Superfamily CYTHERACEA Baird, 1850
Family CYTHERIDEIDAE Sars, 1925
Genus CYTHERIDEA Bosquet, 1852

CYTHERIDEA? ROHRI (Bold)
Plate 3, figs. 1-7

Cyprideis rohri BOLD, 1963, p. 378, pl. 2, figs. 4a, b; pl. 3, figs. 1 a-c; pl. 11, fig. 4; table 5 (part).

Cytheridea rohri (Bold), SANDBERG, 1964, p. 168, pl. 13, fig. 8; BOLD *in* MACSOTAY, 1968, p. 64; BOLD, 1972a, table 2.

Cytheridea? rohri (Bold), BOLD, 1976, p. 31.

Distribution: Talparo Formation, Trinidad; Siquire and Guiria formations, Venezuela.

Remarks: The record of this species from the Gransaul member of the Springvale Formation (Bold, 1963, table 5) is a drafting error, it should have been reported as *Cytheridea mediatena* Bold (1963, p. 376, pl. 2, figs. 3 a-d; pl. 11, fig. 3).

CYTHERIDEA? PURPERAE n. sp.
Plate 1, figs. 7-11

Cyprideis sp. aff. *C. pascagoulaensis* (Mincher), BOLD, 1972, p. 1012.

Diagnosis: A species of *Cytheridea*? with smooth to weakly pitted surface, very shallow submedian sulcus, flattened marginal area in anterior end, obliquely truncate posterior end, and projecting posterior cardinal angle in the left valve.

Description: FEMALE: Left valve in side view elongate subrectangular, highest in the middle third of the carapace. Anterior margin evenly rounded, laterally flattened to a carina; dorsal margin convex, flattened in the middle third where it is parallel to the slightly sinuate ventral margin; posterior margin obliquely rounded, more narrowly rounded below the middle, upper portion obliquely truncate. In the right valve the dorsal margin more strongly convex, posterior end obliquely truncate and narrowly rounded ventrally. Dorsal view with strongly compressed anterior margin, width about equal in anterior and posterior portions with a shallow-compressed area in between. Surface smooth to weakly punctate.

MALE: More elongate and lower; posterior end more obliquely truncate, narrowly rounded ventrally. Marginal area narrow, radial pore canals numerous, evenly spaced, about 30 in anterior end, short, mostly straight, a few bifurcating. Line of conscrescence and inner margin coinciding throughout. Hinge in the left valve with a very elongate anterior socket, about 0.20 mm long and crenulate, anteromedian element a very short tooth, posteromedian element a long (0.25 mm) shallow, crenulate groove, posterior socket short. Muscle scars forming a vertical row of four, located in the submedian sulcus and two small frontal scars, situated close together. Mandibular fulcral point between frontal scars and first and second adductor scars; two small, mandibular muscle-scars located vertically below the frontals.

Dimensions: Tuy Formation: Female left valve: L 0.68 mm, H 0.36 mm; right valve: L 0.64

PLATE 2

Figures

1-2. *Limnocythere* sp. 1, HVH 10787, loc. CB 77-868, Siquire Formation. 75 X. 1, Left valve view; 2, dorsal view.

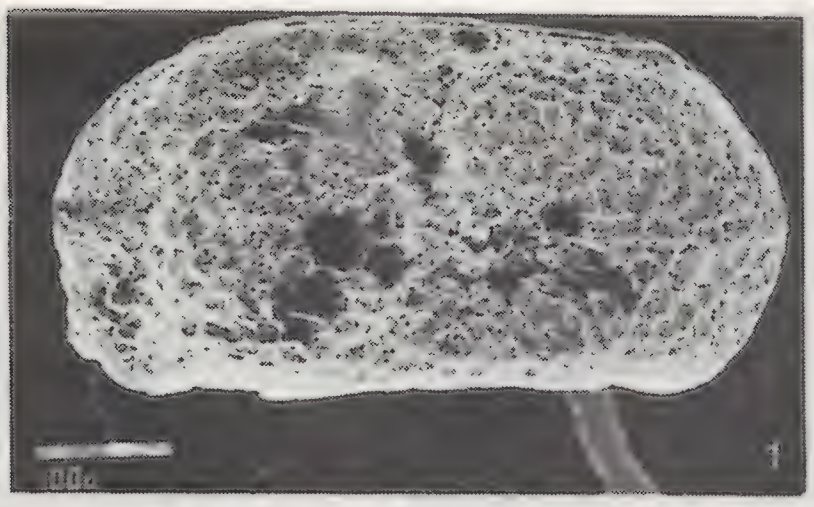
3-4. *Limnocythere* sp. 2, HVH 10789, loc. CB 77-902, Siquire Formation. 3, Left valve view. 100 X; 4, dorsal view. 75 X.

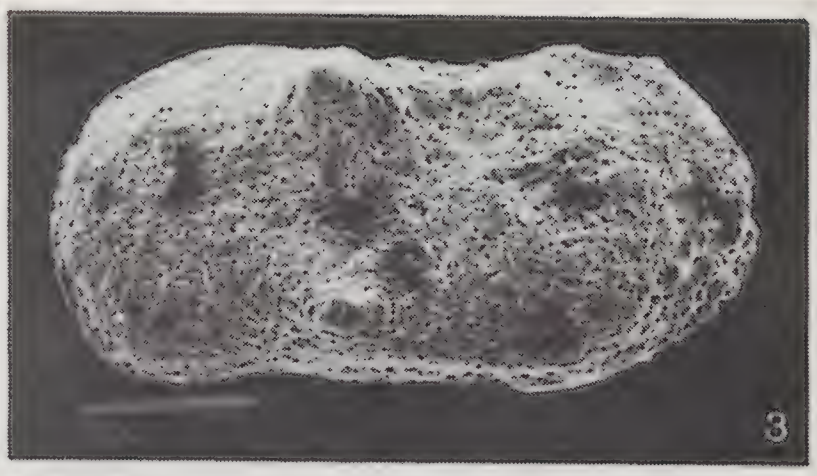
5-6. *Limnocythere* sp. 3, HVH 10750, loc. CB 77-885, Siquire Formation. 85 X. 5, Left valve view; 6, dorsal view.

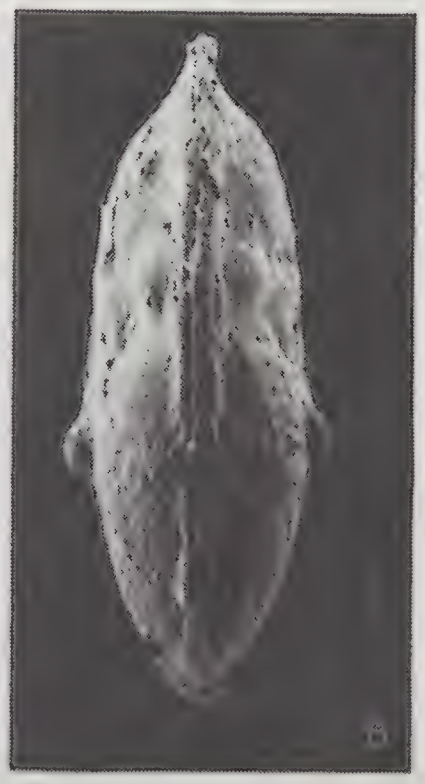
7-8. *Limnocythere* sp. 4, HVH 10752, loc. VB-1, Tuy Formation. 95 X. 7, Left valve view; 8, dorsal view.

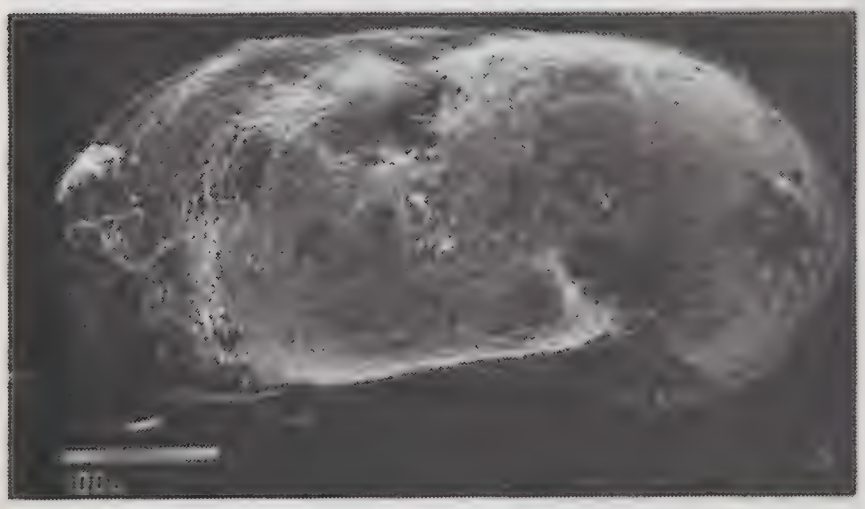
9-10. *Cytheridella boldi* Purper, HVH 10754, loc. CB-77-898, Siquire Formation. 50 X. 9, Right valve view, female; 10, dorsal view, female.

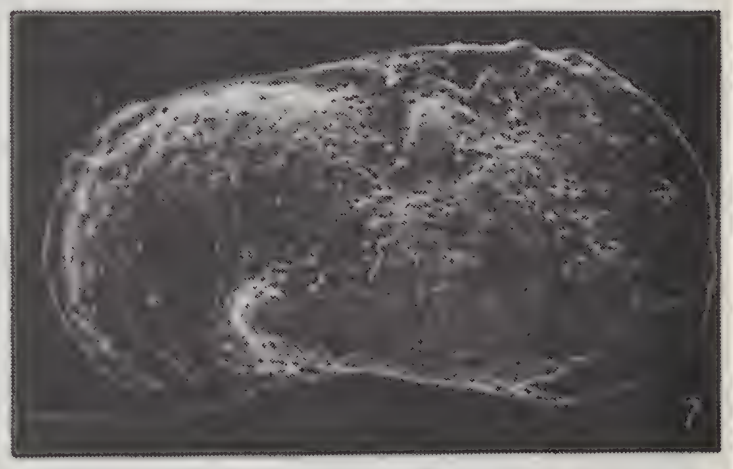
11-13. *Callistocythere? macsotayi*, n. sp., Unit J, Guiria Formation. 11, HVH 10772, right valve view, female, holotype. 75 X; 12, left valve view, female, HVH 10773. 75 X; 13, HVH 10774, right valve view, male. 100 X.

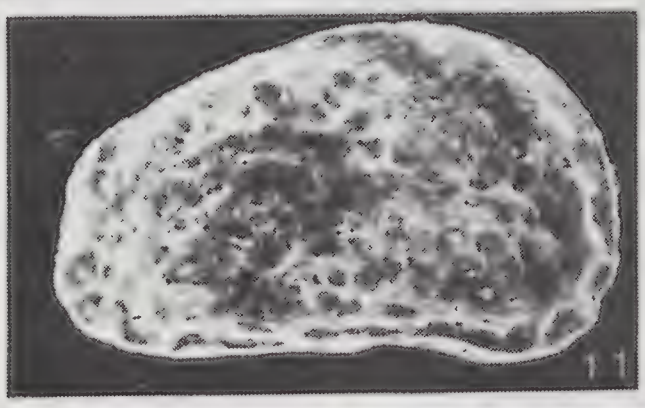


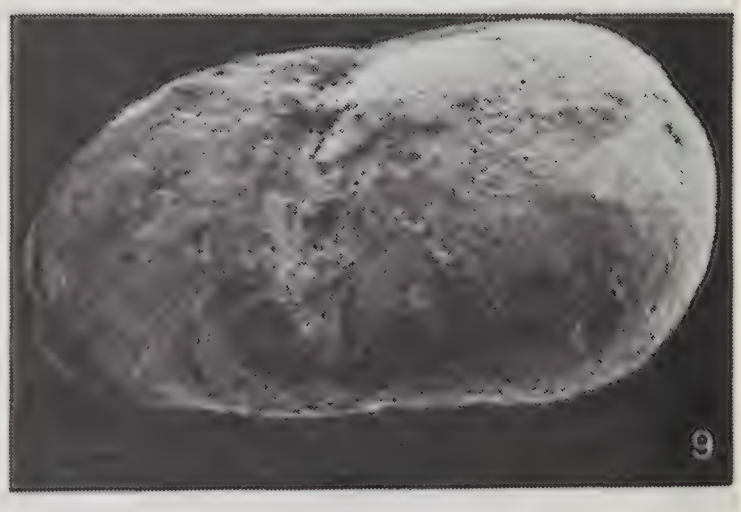


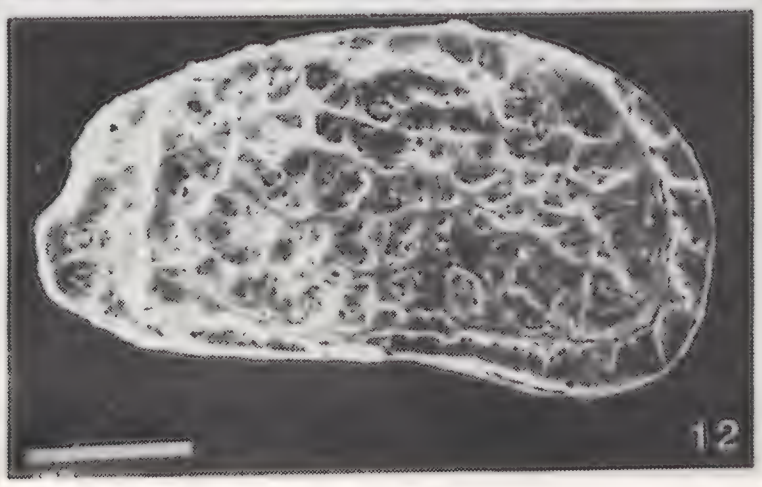












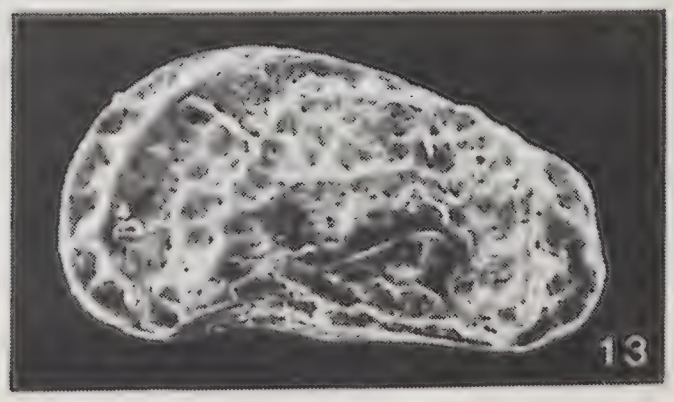


PLATE 2

mm, H 0.34 mm; Male left valve: L 0.77 mm, H 0.38 mm; large female left valve: L 0.72 mm, H 0.36 mm.

Guiria Formation: Female left valve: L 0.67 mm, H 0.36 mm, right valve: L 0.67 mm, H 0.35 mm; Male carapace: L 0.76 mm, H 0.37 mm, W 0.24 mm; left valve: L 0.76 mm, H 0.37 mm.

Name: In honor of Dr. Ivone Purper, Instituto de Geosciencias, Universidade Federal do Rio Grande do Sul, BRASIL.

Holotype: HVH no. 10755: right valve, female.

Paratypes: Male and female left and right valves: HVH nos. 10756-10760.

Type locality: VB-1 (Coll. P. J. Bermúdez), roadcut between Charallava and Santa Teresa, Estado Miranda, Venezuela (Bermúdez, 1966, p. 344).

Stratigraphic horizon: Tuy Formation.

Distribution: Upper part of Siquire Formation, Tuy Formation, upper part of Guiria Formation (Unit E).

Remarks: Cytheridea? purperae differs in some respects from typical *Cytheridea* and can only be assigned questionably to this genus. It probably does not belong to the "*Cytheridea*" group that developed in northern Venezuela and Trinadad from a stock of questionable *Hemicyprideis*? species (e.g., *Hemicyprideis? cagigalensis)*. (See Bold, 1976, p. 31 for discussion.) *Cytheridea pebasae* Purper (1979, p. 228, pl. 2, figs. 11-25) is similar in size and in side view outline, but more rectangular in dorsal view and has a more distinctly pitted surface and a dentate anterior end. Sheppard and Bate (1980) combined this species with *Cytheridea graciosa* Purper and *Cytheridea longispina* Purper under the name *Cyprideis purperi purperi* (1980, p. 99, pl. 7, figs. 1-13). Ivone Purper compared some of my specimens with her Brasilian material and concluded that although similar the two species are not identical (letter 16 March, 1979).

Family LIMNOCYTHERIDAE Klie, 1938
Genus LIMNOCYTHERE Brady, 1868

In the Sta. Lucia-Ocumare del Tuy basin four species of *Limnocythere* occur. Originally it was thought that two of the species might be molts of the other two, but all four show distinct sexual dimorphism. These species are not named because I do not have exact localities and the interior could not be studied.

LIMNOCYTHERE sp. 1
Plate 2, figs. 1-2

Description: Carapace subrectangular in side view, dorsal and ventral margin roughly parallel. Anterior margin evenly rounded, posterior margin bluntly angled in the middle, obliquely truncate above and below. Lower part of posterior margin extending below the ventral margin with a small notch just in front of the posteroventral angulation. Ventral surface concave. Surface finely reticulate. Subcentrally a deep median sulcus separating an anterocentral and a posterodorsal swelling. A posteroventral swelling with a broad knob, separated from the posterodorsal swelling by a shallow depression. From the middle of the subcentral sulcus a shallower sulcus extends upward and foreward, enclosing a small knob, separated from the inconspicuous eye-node by a shallow depression. Dorsal view irregular in outline with compressed anterior end, greatest width at the node of the posteroventral swelling at about 1/5 of the length from the posterior extremity. Interior not studied. Male much more elongate, highest in

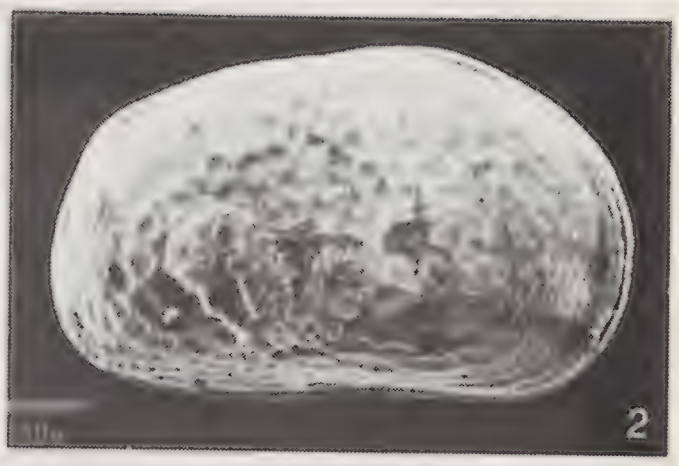
PLATE 3

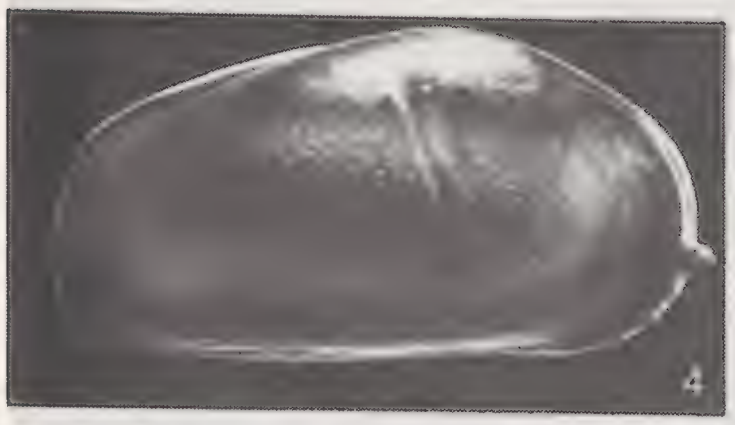
Figures

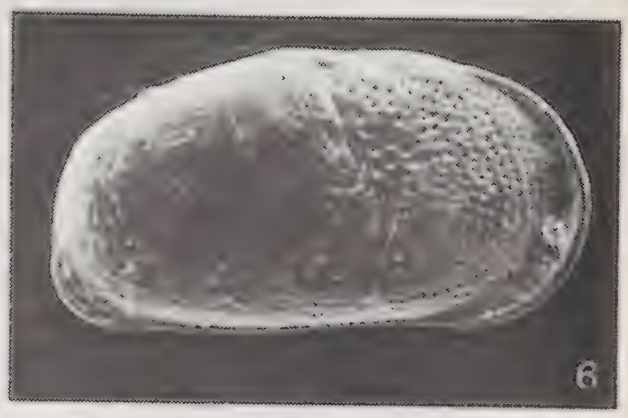
1-7. *Cytheridea rohri* (Bold). 1, HVH 10761, right valve view, female, loc. CB 77-885, Siquire Formation. 50 X; 2, HVH 10762, right valve view, female, loc. CB 77-898, Siquire Formation. 50 X; 3, HVH 10763, dorsal view, female loc. CB 77-885, Siquire Formation. 50 X; 4, HVH 10764, right valve view, male, loc. CB 77-885, Siquire Formation. 50 X; 5, HVH 10765, dorsal view, male, loc. CB 77-885, Siquire Formation. 50 X; 6, HVH 10766, right valve, male, Unit J, Guiria Formation. 50X; 7, HVH 10767, left valve, male, Unit J, Guiria Formation. 60 X.

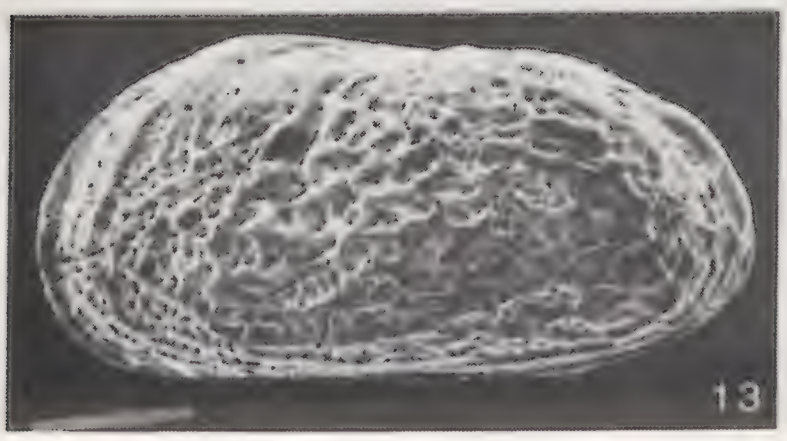
8-11. *Xestoleberis bermudezi* n. sp., Unit J, Guiria Formation. 110 X. 8, HVH 10776, holotype, right valve view, female; 9, HVH 10777, dorsal view, female; 10, HVH 10778, right valve view, male; 11, HVH 10779, dorsal view, male.

12-15. *Perissocytheridea cytheridellaformis* Forester, Unit J, Guiria Formation. 12, HVH 10769, right valve view, female 80 X; 13, HVH 10769, left valve view, male. 85 X; 14, HVH 10769, dorsal view, female. 80 X; 15, HVH 10769, dorsal view, male. 85 X.









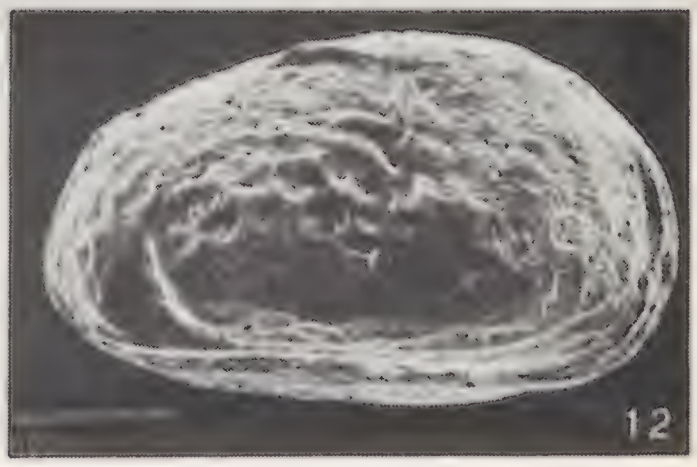


PLATE 3

the posterior fourth with anteriorly converging dorsal and ventral margins.

Dimensions: Female: L 0.61 mm, H 0.33 mm, W 0.28 mm; Male: L 0.73 mm, H 0.36 mm, W 0.27 mm.

Distribution: Basal Siquire Formation.

LIMNOCYTHERE sp. 2
Plate 2, figs. 3-4

Description: Very similar in side view to *Limnocythere* sp. 1, but much smaller; posterior and more regularly rounded. Node on ventral swelling the most conspicuous tubercle at 0.36 of the length from the posterior extremity; greatest width in this position. Almost vertically above it a dorsal node; both very prominent in dorsal view. This species is believed to be a descendant of *Limnocythere* sp. 1.

Dimensions: Female: L 0.43 mm, H 0.23 mm, W 0.26 mm; Male: L 0.46 mm, H 0.23 mm, W 0.20 mm.

Distribution: Upper Siquire Formation.

LIMNOCYTHERE sp. 3
Plate 2, figs. 5-6

Description: Carapace in side view subrectangular. Anterior margin almost regularly rounded, dorsal margin straight, ventral margin strongly concave, posterior margin rounded in the middle, gently convex above and below. A vertical subcentral sulcus containing the adductor scars; a shallow depression at the place of attachment of the frontal muscles. Central part of the carapace swollen, the ventral termination of the swelling converging posteriorly towards the dorsal margin and ending abruptly at about 1/3 of the length from the posterior extremity in front of a depressed area. Behind this the carapace exhibits a posteroventral swelling connected to a posterodorsal swelling. Only one carapace with very weak reticulation, others smooth. Dorsal view narrow, spindle-shaped, ends compressed, especially the anterior. Greatest width at the posterior end of the ventral swelling at 1/3 of the length from the posterior; in the male the greatest width at about 1/4. Males longer and having the greatest height in the posterior fourth of the carapace. Dorsal and ventral margin converging anteriorly.

Dimensions: Female: L 0.59 mm, H 0.28 mm, W 0.22 mm; Male: L 0.63 mm, H 0.27 mm, W 0.20 mm.

Distribution: Lower Siguire Formation.

Remarks: Similar in general appearance to *L. sappaensis* Staplin (1963, p. 1197, pl. 160, figs. 4-6) from the Pleistocene of South Dakota, Nebraska, Iowa, and Kansas but that species is more clearly reticulate and lacks the posteroventral swelling.

LIMNOCYTHERE sp. 4
Plate 2, figs. 7-8

Description: Very similar to sp. 3, but much smaller. In the female the posterior end of the ventral swelling projects laterally as a tubercle.

Dimensions: Female: L 0.44 mm, H 0.23 mm, W 0.20 mm; Male: L 0.51 mm, H 0.25 mm.

Distribution: Tuy Formation.

LIMNOCYTHERE STAPLINI Gutentag and Benson

Limnocythere staplini GUTENTAG and BENSON, 1962, p. 51, pl. 1, figs. 1-3, text-fig. 15; BOLD, 1975a, p. 612, pl. 59, fig. 8a, b.

Limnocythere sp. BOLD, 1972a, p. 1012.

Dimensions: L 0.57 mm, H 0.30 mm (HVH 10753).

Distribution: Pleistocene, Kansas; Las Salinas and Jimaní Formations (Late Pliocene to Pleistocene?) Hispaniola; Cumaca Formation, Venezuela; Recent, Bahamas, North America.

Genus CYTHERIDELLA Daday, 1905

CYTHERIDELLA BOLDI Purper
Plate 2, figs. 9-10

Cytheridella boldi PURPER, 1974, p. 654, pl. 10, figs. 1-4.

Cytheridella ilosvayi Daday, BOLD, 1975a, p. 613, pl. 58, fig. 1 a-g; pl. 6, fig. 3a, b (not DADAY, 1905).

Dimensions: Female: L 0.87 mm, H 0.49 mm, W 0.60 mm; Male: L 0.86 mm, H 0.47 mm, W 0.48 mm.

Distribution: Siquire Formation, Recent, Lago de Valencia, Venezuela; upper Talparo Formation, Trinidad; Jimaní Formation, Hispaniola.

Remarks: The specimens from the Siquire Formation and from cuttings of a well (material from M. Dempsey) in the Talparo Formation (northern - basin, Trinidad) are all slightly distorted, but show the typical "square" posterior portion of the female, different from C. *ilosvayi* and C. *danielopoli* Purper (1979, p. 243, pl. 7, figs. 21-27). I am not certain if the distinct pattern of pitting in C. *postornata* Sheppard and Bate (1980, p. 108, pl. 10, figs. 1-7) is sufficient to separate this species from C. *danielopoli*. Typical (but again distorted) specimens of C. *postornata* have been found in the "*Chara* zone" of Huila (Colombia), where they occur together with specimens of *Darwinula fragilis* Purper, *Cypria aequalica* Sheppard and Bate, *Pelocypris zilchi* Triebel,

Proparacytheridea acuminata Purper, *Perissocytheridea* n. sp., and *Pacambocythere campana* (Sheppard and Bate) (=*Ambocythere? campana* Sheppard and Bate, 1980, p. 110, pl. 11, figs. 1-9), which is the most common ostracode there (Pl. 1, fig. 12). This suggests a possible correlation of the "*Chara* zone" with the Pebas Formation and its southeast Colombian equivalents.

Family CYTHERIDAE Baird, 1850
Subfamily PERISSOCYTHERIDEINAE Bold, 1963
Genus PERISSOCYTHERIDEA Stephenson, 1938

PERISSOCYTHERIDEA SUBROGOSA (Brady)
Plate 1, figs. 13-14

Cythere subrugosa BRADY, 1870, p. 238, pl. 30, figs. 18, 19.

Perissocytheridea subrugosa (Brady), BOLD, 1958a, p. 71, tables 1, 3; 1963, p. 380, pl. 4, fig. 2 a-d; 1966, pl. 1, fig. 7 a, b; TEETER, 1975, p. 432, figs. 6 j, 7 f, g; BOLD, 1978 b, table 9.

Distribution: Pliocene to Recent: Greater Antilles, Northern South America, Costa Rica; Lower Guiria Formation, Venezuela.

PERISSOCYTHERIDEA CYTHERIDELLAFORMIS Forester
Plate 3, figs. 12-15

Perissocytheridea n. sp. BOLD *in* MACSOTAY 1968, p. 64.

Perissocytheridea cytheridellaformis FORESTER *in* BOLD, 1975a, pp. 610, 818, pl. 60, fig. 8 a-e; pl. 61, fig. 1 a, b; pl 62, fig. 1 a, b, tables 3, 6, 7.

Distribution: Upper Las Salinas Formation, Hispaniola; lower Guiria Formation, Venezuela.

Family LEPTOCYTHERIDAE Haai, 1957
Genus CALLISTOCYTHERE Ruggieri, 1953

CALLISTOCYTHERE? MACSOTAYI n. sp.
Plate 2, figs. 11-13

Diagnosis: A species of *Callistocythere*? with a prominent, vertical, posterior ridge.

Description: Carapace in side view trapezoid to subrectangular, highest at 2/5 of the length from the anterior extremity. Anterior margin obliquely rounded, dorsal margin gently convex, ventral margin sinuate, converging posteriorly; posterior margin steeply truncate above, narrowly rounded ventrally. Ventral and dorsal surface flattened, but only barely delineated by longitudinal ridges. Surface irregularly reticulate. A pronounced anterior rim paralleling the anterior margin with 5-6 radial ridges projecting forward toward the margin. At 1/7 of the length from the posterior extremity a vertical ridge, the carapace strongly compressed behind. Weak ventral, dorsal and subdorsal ridges extend forward from the posterior ridge, becoming obscure in the middle of the valve. Dorsal view wedge-shaped, widest just in front of the posterior ridge.

Sexual dimorphism present. Male elongate-trapezoid in side view, lower and narrower than the female, with dorsal and ventral margin more nearly parallel in the posterior half. Greatest width at the posterior ridge. Interior not observed. Only closed carapaces were found.

Dimensions: Female: L 0.46 mm, H 0.26 mm, W 0.18 mm; Male: L 0.43 mm, H 0.21 mm, W 0.26 mm.

Name: After Oliver Macsotay, Oceanographic Institute, University of Oriente, Venezuela, in honor of his work on the Guiria, Siquire and Tuy formations.

Holotype: HVH no. 10772, female carapace.

Paratypes: HVH no. 10773-10775, male and female carapaces.

Type locality: Sample 496a (Macsotay, 1968, p. 55), in small ravine 500 m NE of the stone pier at Guiria.

Distribution: Only in Unit J of the Guiria Formation.

Remarks: This species differs from other species of *Callistocythere* described from the Atlantic and Pacific coast of America by having a vertical posterior ridge instead of the general gradual curvature of ridges in the posterior end.

Family TRACHYLEBERIDIDAE Sylvester-Bradley, 1948
Subfamily TRACHYLEBERIDINAE Sylvester-Bradley, 1948
Genus CATIVELLA Joryell and Fields, 1938

CATIVELLA PULLEYI Teeter

Cativella aff. *semitranslucens* (Crouch), BOLD, 1958b, p. 404, pl. 3, fig. 3; 1963, p. 389, pl. 11, fig. 6; 1978b, table 9.

Cativella pulleyi TEETER, 1975, p. 451, figs. 12 f, 12 c-e; BREMAN, 1982, pl. 4, fig. h.

Distribution: Middle Miocene to Recent: Carribbean; Unit J of the Guiria Formation, Venezuela.

Subfamily CAMPYLOCYTHERINAE Puri, 1960
Genus BASSLERITES Howe, 1937

BASSLERITES MINUTUS Bold

Basslerites minutus BOLD, 1956, p. 405, pl. 3, fig. 8; pl. 5, fig. 5 a-c; MORALES, 1966, p. 62, pl. 5, fig. 3 a, b; BREMAN, 1982, p. 237.

Distribution: Lower Miocene to Recent, Caribbean; Unit J of the Guiria Formation, Venezuela.

Family LOXOCONCHIDAE Sars, 1925
Genus LOXOCONCHA Sars, 1965
LOXOCONCHA LEVIS Brady

Loxoconcha levis BRADY, 1870, pp. 238, 242, pl. 32, figs. 7, 8; BOLD, 1963, p. 393, pl. 9, fig. 10 a, b; TEETER, 1975, p. 473, fig. 18g, 19 a, b; BOLD, 1968, pp. 22, 25, 30; 1975a, pp. 577, 578, 583, 585, 590, 604; 1975b, pp. 122, 127; 1978, table 9; 1981, p. 81, pl. 5, fig. 11 a, b.

Distribution: Pliocene to Recent, Caribbean; Unit J of the Guiria Formation, Venezuela.

Family XESTOLEBERIDIDAE Sars, 1928
Genus XESTOLEBERIS Sars, 1866
XESTOLEBERIS BERMUDEZI n. sp.
Plate 3, figs. 8-11

Description: FEMALE: In side view almost forming a 120 degree circle-sector, elongate, highest at 3/5 of the length from the anterior extremity. Anterior margin with dorsal slope from the greatest height, narrowly rounded ventrally; dorsal margin short, gently convex, converging to ventral posteriorly; posterior margin rounded subventrally, dorsal slope steep and slightly convex. Ventral surface strongly flattened, somewhat concave. Dorsal view bullet-shaped, widest at 1/3 of the length from the posterior end, acuminate anteriorly, broadly rounded posteriorly.

MALE: Similar in shape but lower in side view, greatest height just behind the middle, slope of the dorsal part of posterior margin less steep than in female, more narrowly rounded ventrally. Dorsal view widest in the middle, posterior end less broadly rounded than in female.

Dimensions: Female: L 0.38 mm, H 0.19 mm, W 0.23 mm; Male: L 0.35 mm, H 0.16 mm, W 0.19 mm.

Name: After the late Dr. P. J. Bermúdez.

Holotype: HVH No. 10776, female carapace.

Paratypes: HVH No. 10777 (female carapace), 10778, 10779 (male carapaces).

Type locality: 496a of Macsotay, 1968, p. 55, in small ravine, 500m NE of the stone pier at Guiria.

Stratigraphic horizon: Base of Unit J of Macsotay, Guiria Formation.

Distribution: Only in Unit J of the Guiria Formation.

Remarks: The species is similar in side view to *X. chilensis* Hartmann (1962, p. 219, figs. 118-130), but has the greatest height more posteriorly. In dorsal view, the greatest width is also more posteriorly. In side-view it is almost a duplicate of *X. tomkilenyii* Bate *et al.*, 1982 (p. 68, pl. 68, figs. 42 K-S, 43 A-Q, 44F) from the Galapagos islands, except for the lack of posteroventral nodes. The male, however, is more tapering posteriorly in side-view.

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December 15, 1986

VIGNETTES OF COASTAL PLAIN GEOLOGY

ARTHUR CLIFFORD VEATCH
(1878-1938)

Arthur Clifford Veatch entered Cornell University in 1898, where Gilbert D. Harris was Professor of Geology. Also, at the same time, Harris was Geologist-in-Charge of the Louisiana State Geological Survey. Harris soon recognized Veatch's exceptional talents and appointed him Assistant State Geologist of Louisiana in 1899. The next two field seasons were spent in Louisiana, and this work resulted in a series of papers by Harris and Veatch. After a brief term as Professor of Geology at Louisiana State University, Veatch went to work for the United States Geological Survey in 1902; his later works on the geology of Arkansas and Louisiana being one result of this association. (*From* W. E. Heroy, 1942, Geological Society of America, Proceedings)

TULANE STUDIES IN GEOLOGY AND PALEONTOLOGY

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MYTILIDAE (MOLLUSCA: BIVALVIA) FROM THE CHIPOLA FORMATION, LOWER MIOCENE, FLORIDA

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I. ABSTRACT

The bivalve family Mytilidae, previously known from the Chipola Formation by only a few, mostly fragmentary specimens referable to three species, proves to be relatively widely distributed throughout the type area of the formation, being most abundant in localities where coral is also present.

In this paper, ten species in eight genera are reported from the formation. Included are three new species and one new subspecies.

II. INTRODUCTION

Species of the family Mytilidae exhibit a preference for intertidal and shallow-water environments, including: (a) rocky areas, permitting byssal attachment (Mytilinae); or burrowing into rocks, corals or larger shells (*Gregariella, Botula*, most *Lithophaga*); or (b) mud flats for burrowing (Modiolinae). The principal exception to these preferences is afforded by the species of the genus *Crenella*, which are most commonly found on muddy silt or sand bottoms. Living specimens have been taken from depths down to 460 meters in the Pacific Ocean (Bernard, 1983, p. 20) and what obviously were dead valves have been reported from depths as great as 2,290 fathoms [=4,076 meters] (Clarke, 1962, p. 58).

This general preference of most mytiloid forms for shallow-water and intertidal hard-bottom environments where dead shells tend to be destroyed by wave action, has resulted in their being relatively rare elements in the fossil faunas, with *Crenella* being apparently the most widely distributed genus. Thus, it is of considerable interest to find in the Tulane University collections from the type area of the Lower Miocene Chipola formation of northern Florida, ten species referable to eight genera, including each of the four recognized subfamilies (Table 1).

In contrast, prior to this report, Dall (1898b, p. 797) listed only "*Modiolus (Botula) cinnamomeus* Lamarck" [=*Botula fusca* (Gmelin)] and (p. 806) "a single broken valve," identified as "*Modiolaria* sp. indet." [=*Musculus (Ryenella) lateralis praelateralis* n. subsp.]. At the same time, however, he described *Modiolus (Brachydontes) grammatus* var. *curtulus* (p. 794) and *Crenella miniscula* (p. 803) from the lower bed at Alum Bluff on the Apalachicola River, which contains a fauna that appears to be equivalent to that of the uppermost beds of the Chipola Formation on the Chipola River. Gardner (1926, p. 60) reported the occurrence of *Crenella* in the beds at the McClelland Farm on the Chipola River and from Tenmile Creek. Tulane University collections contain more than 700 specimens of *C.*

miniscula from 52 of our 57 Chipola localities.

III. SYSTEMATIC PALEONTOLOGY

Superfamily MYTILACEA Rafinesque, 1815

Family MYTILIDAE Rafinesque, 1815

Subfamily MYTILINAE Rafinesque, 1815

Genus PERNA "Retzius," Philipsson, 1788 [ICZN Op. 495]

Perna "Retzius" PHILIPSSON 1788, Disert. Hist. Nat. Nova Testac. Genera, p. 20.

Chloromya MÖRCH, 1853, Cat. Conch. Yoldi, pt. 2, p. 52.

?*Mytiloconcha* CONRAD, 1862, Acad. Nat. Sci. Phila., Proc., v. 14, p. 290 [as *Mytiliconcha*, p. 579].

Type species, by subsequent designation, Soot-Ryen, 1955: *Perna magellanica* "Retzius" (=*Mya perna* Linnaeus, 1758). Recent, Straits of Magellan (Type locality, *fide* Soot-Ryen, 1955, p. 30), north to Venezuela (Rios, 1975, p. 197); South Africa from Namibia to Mozambique (Kilburn and Rippey, 1982, p. 159).

Discussion: Species referable to the genus *Perna* may be recognized by their dysodont hinge, consisting of one or two small denticles close to the beak, by their pitted resilial ridge below the ligament, and by their margaritaceous shell structure. The latter tends to weaken the rather thin shells to the point that they are seldom found well-preserved in the fossil record.

The generic name *Perna* usually has been cited as having been proposed by Retzius in 1788, but as was noted by A. E. Ellis in his request to the International Commission on Zoological Nomenclature concerning the genus *Unio* (see Opinion 495, 1957), "This genus was established in a thesis by Philipsson, working under his master Retzius at the University of Lund. By the law or custom then obtaining the professor was treated as the author of all papers which a student under him defended. For this reason the . . . names in this thesis have been attributed . . . to Retzius. It is clear, however, from the title page that Philipsson was the real author of this *Dissertatio* and that the name *Unio* is therefore correctly attributable to him and not to Retzius."

PERNA CRAURA H. E. Vokes, n. sp.

Plate 1, Figures 1-3

Description: Shell of medium size, mytiliform, with obliquely elongated, moderately convex valves marked by a rounded umbonal ridge paralleling the anterior margin; umbones relatively small, terminal, pointed; posterior margin slightly convex, almost straight along the length of the ligament, then sharply and subangulately

TABLE 1. DISTRIBUTION OF MYTILOID SPECIES IN THE CHIPOLA FORMATION

	CHIPOLA RIVER	TENMILE CREEK	FARLEY CREEK	Total Number of Localities
Number of localities with mytiloid specimens	21	19	15	55
MYTILINAE				
Perna craura n. sp.	6	0	10	16
Brachidontes curtulus (Dall)	5	0	15	20
CRENELLINAE				
Crenella miniscula Dall	19	10	15	52
Musculus (Planimodiola) disinflatus n. sp.	9	0	10	19
M. (Ryenella) lateralis praelateralis n. subsp.	15	14	14	43
Gregariella arcaforma n. sp.	2	3	2	7
LITHOPHAGINAE				
Lithophaga antillarum (Orbigny)	0	1	3	4
L. (Diberus) bisulcata (Orbigny)	2	1	4	7
MODIOLINAE				
Modiolus ducatelii Conrad	5	2	6	13
M. sp. (immature *ducatelii* ?)	6	6	10	22
Botula fusca (Gmelin)	1	1	1	3

curved into a relatively straight postero-ventral slope that gradually rounds into the ventral end and curves rather sharply around termination of umbonal ridge to pass into the concave anterior slope. Surface smooth, marked only by growth lines that occasionally develop into low lamellae toward outer margins. Hinge below beaks, small, subtriangular, apparently formed by folded edge of obscure lunule, marked by small, elongated ridge-like teeth, usually one, with or without a tiny rounded node across the anterior adjacent groove that receives one of the two teeth of the opposite valve; resilial ridge finely pitted along its entire length; inner margins of valve smooth; muscular pattern not well-preserved, but appears to be similar to that of specimens of *Perna perna* (Linné).

Holotype: USNM 407799; length 36.4 mm, width 22.1 mm, diameter (right valve) 6.2 mm. Type locality: TU 459, Chipola River, Calhoun County, Florida.

Paratype A: USNM 407800; length 13.0 mm, width 6.9 mm, diameter (right valve) 1.9 mm; locality TU 459, Chipola River, Calhoun County, Florida.

Paratype B: USNM 407801; length (incomplete) 50.4 mm, width *ca.* 26.5 mm, diameter (left valve) 17.6 mm; locality TU 1048, Farley Creek, Calhoun County, Florida.

Discussion: Insofar as the writer is aware this is the first species of true *Perna* to be reported from the fossil faunas of the eastern United States. The name has been used in the past, however, in the sense of *Perna* Bruguière (1789, p. 13; = *Isognomon* Solander *in* Lightfoot, 1786) or of H. and A. Adams (1857, p. 515, as *Perna* Adanson, a pre-Linnaean name; = *Modiolus* Lamarck).

Woodring (1973, p. 522) noted that casts from the Culebra Formation of Panamá, which he identified as *Mytilus canoasensis* [Olsson] *vidali* Ferreira and Cunha (1959, p. 22, pl. 2, figs. 1a, b; described from the Lower Miocene Pirabas Formation of northern Brazil) show the impression of pits on the resilial ridge. This would appear to be second western Atlantic fossil species of the genus.

Perna craura, n. sp., is represented in the Chipola collections by a large number of specimens, with all except the smaller valves being broken and incomplete. The largest broken valve, from TU 548 on the Chipola River, if complete, would have had a length of about 82 mm, and a width slightly in excess of 45 mm.

The number of "teeth" in the hinge area varies greatly between specimens; a count of some forty apical areas of valves from TU 459 revealed that almost one-half of the right valves had one "tooth," plus a marginal node, with the other half having two "teeth;" there was a similar distribution on the left valve.

The form described and figured by Maury (1910, p. 33, pl. 8, fig. 8) as *Perna solereperta* and based upon an incomplete valve from the Oak Grove Formation, in Santa Rosa County, Florida, is clearly not related to the present species, in which none of the more than 200 mostly incomplete valves show any trace of radiating riblets. The writer actually is not aware of any described species of *Perna* so ornamented. The "two . . . cartilage pits" cited by Maury may possibly represent remnant marginal crenulation resulting from the radial ornament; similar structures are known from *Brachidontes*, *Aulacomya* and other mytiloid genera.

The specific name *craura* is derived from the Greek term "Krauros," meaning brittle or friable, and is applied in allusion to the fragile nature of the fossil valves.

Genus BRACHIDONTES Swainson, 1840

Brachidontes SWAINSON, 1840, Treat. Malac., p. 384.

"*Brachydontes*, Swains., 1840" GRAY, 1847, Zool. Soc. London, Proc., v. 15, p. 199.

Brachyodontes AGASSIZ, 1846, Nomen. Zool. Index Univ., p. 51 (emend. pro *Brachidontes* Swainson).

Type species, by monotypy, *Modiola sulcata* Lamarck, 1819 [*non* Lamarck, 1805] = *Arca modiolus* Linnaeus, 1767 = *Mytilus citrinus* Röding, 1798. Recent, southern Florida, Yucatan Peninsula and West Indies.

BRACHIDONTES CURTULUS (Dall)
Plate 1, Figures 4, 5

Modiolus (Brachydontes) grammatus var. *curtulus* DALL, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 794.

Modiolus (Brachidontes) curtulus Dall. GARDNER, 1926, U. S. Geol. Surv., Prof. Paper 142-A, p. 58, pl. 15, fig. 4.

Description: "Shell small but quite solid, cuneate in outine, attenuated toward the umbones; flaring and obtusely angulated along posterior margin, the anterior margin straight or feebly concave, the base line broadly rounded.

Umbones very small, subacute, almost but not quite terminal. Radials along the posterior and ventral margins coarse, heavily corrugated by the incrementals, tending to bifurcate toward the outer margin, not far from 15 in number, those upon the anterior slope almost twice that number and consequently much finer and more crowded and not dichotomous. Ligament groove moderately deep. Hinge edentulous. Adductor scar obscure. Inner margins crenate in harmony with the external sculpture, nearly obsolete toward the umbones." (Gardner, 1926)

Holotype: USNM 114578.

Type locality: USGS 2211, Alum Bluff (lower bed), Liberty County, Florida.

Figured specimen: USNM 407802; maximum length 7.0 mm, height 4.0 mm, right valve; locality TU 548, Chipola River, Calhoun County, Florida.

Figured specimen: USNM 407803; maximum length 6.0 mm, height 3.6 mm, left valve; locality TU 548, Chipola River, Calhoun County, Florida.

Discussion: Dall (1898b) described *curtulus* as a variety of his new species *Modiolus (Brachydontes) grammatus*, the type of which came from Ballast Point, Tampa Bay, Florida. He apparently had but one valve, which was subsequently figured by

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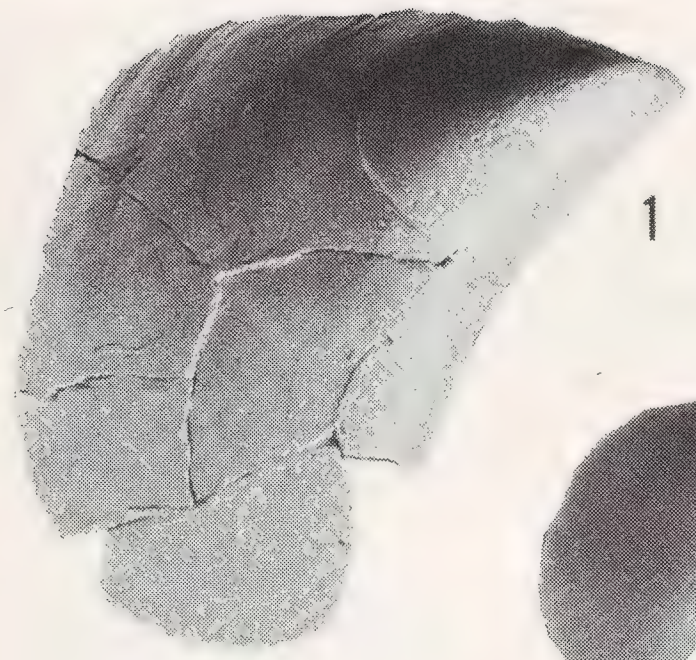
PLATE 1

Figures Page

1-3. *Perna craura* H. E. Vokes, n. sp. 160
1. Holotype, USNM 407799 (X 1.5); length 36.4 mm, width 22.1 mm. Locality: TU 459, Chipola River.
2. Paratype A, USNM 407800 (X 2); length 13.0 mm, width 6.9 mm. Locality: TU 459, Chipola River.
3. Paratype B, USNM 407801 (X 5.5); view of incomplete specimen, showing pitted resilial ridge. Locality: TU 1048, Farley Creek.
4, 5. *Brachidontes curtulus* (Dall). 161
4. Figured specimen, USNM 407802 (X 6); length 7.0 mm, height 4.0 mm. Locality: TU 548, Chipola River.
5. Figured specimen, USNM 407803 (X 6); length 6.0 mm, height 3.6 mm. Locality: TU 548, Chipola River.
6, 7. *Crenella miniscula* Dall 164
6. Figured specimen, USNM 407804 (X 13); height 2.9 mm, length 2.0 mm. Locality: TU 70, Tenmile Creek.
7. Figured specimen, USNM 407805 (X 13); height 2.3 mm, length 2.0 mm. Locality: TU 549, Chipola River
8, 9. *Musculus (Planimodiola) disinflatus* H. E. Vokes, n. sp. 169
Holotype, USNM 407813 (X 6); length 6.6 mm, height 3.4 mm (fig. 8, right valve; fig. 9, left valve). Locality: TU 458, Chipola River.
10, 11. *Musculus (Ryenella) lateralis praelateralis* H. E. Vokes, n. subsp. 165
10. Holotype, USNM 407806 (X 4); length 10.0 mm, height 6.0 mm. Locality: TU 825, Farley Creek.
11. Paratype, USNM 407807 (X 5); length 5.8 mm, height 4.1 mm. Locality: TU 196, Tenmile Creek.
12, 13. *Botula fusca* (Gmelin). 172
12. Figured specimen, USNM 407808 (X 3.5); length 10.1 mm, height 8.2 mm. Locality: TU 547, Chipola River.
13. Figured specimen, USNM 407809 (X 2); length 26.0 mm, height 12.8 mm. Locality: TU 1048, Farley Creek.
14, 15. *Gregariella arcaforma* H. E. Vokes, n. sp. 169
Holotype, USNM 407810 (X 5); length 9.9 mm, height 4.9 mm (fig. 14, external view, left valve; fig. 15, hinge and interior, right valve). Locality: TU 1196, Farley Creek.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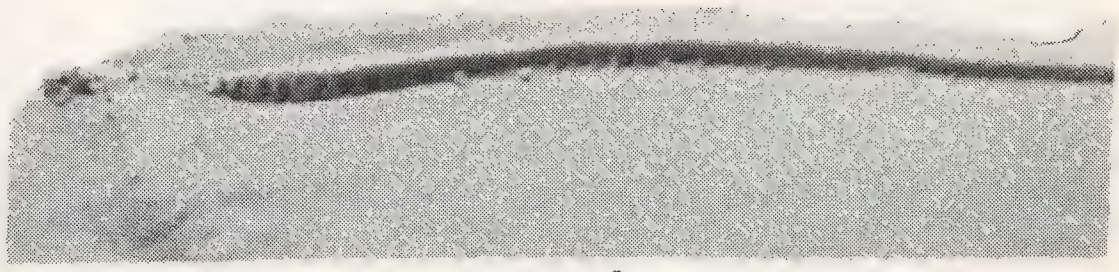
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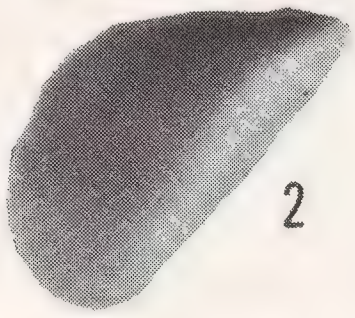
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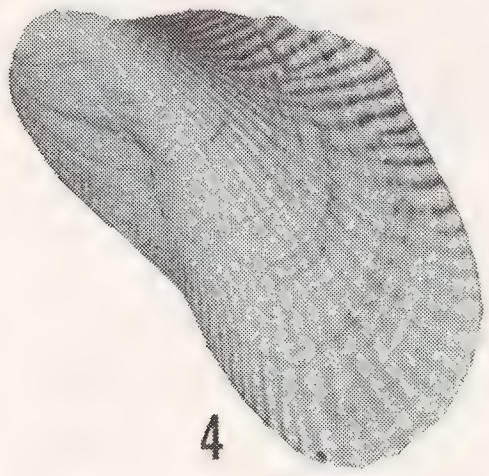
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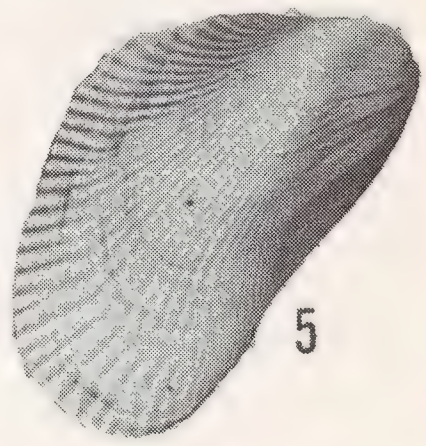
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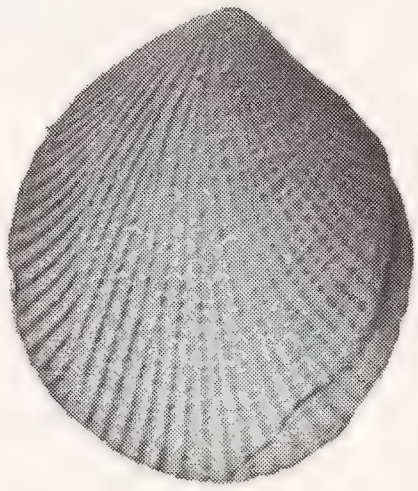
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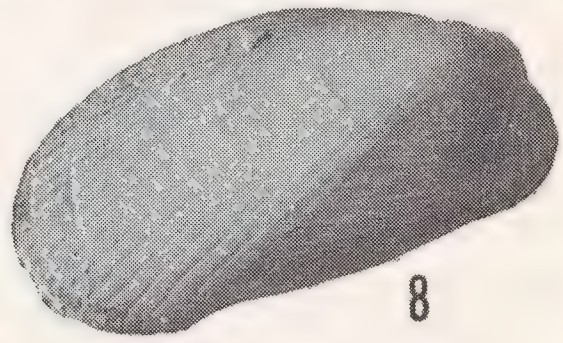
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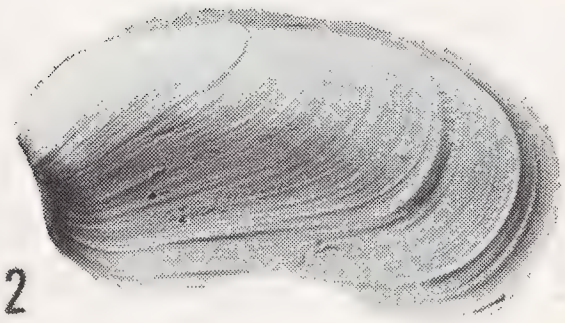
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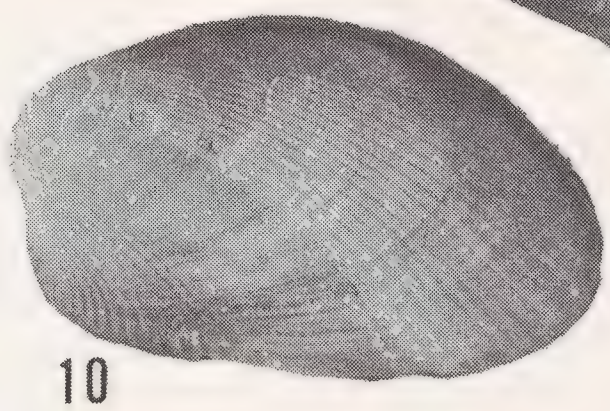
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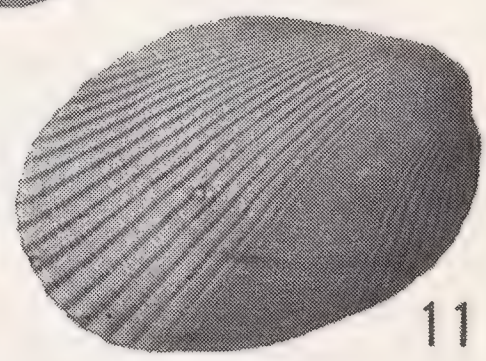
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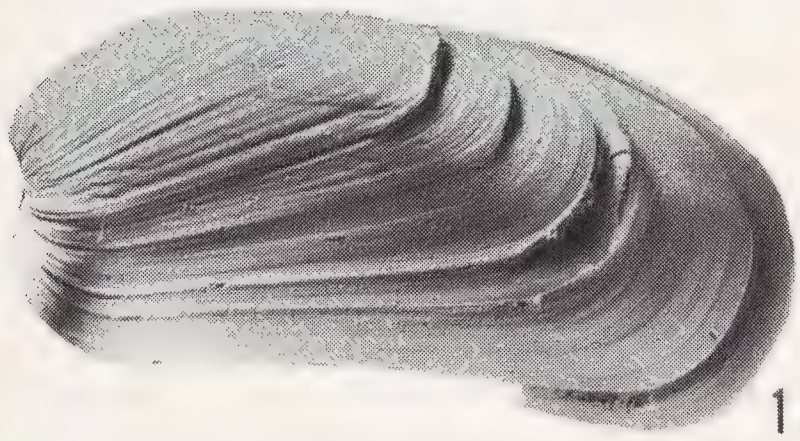
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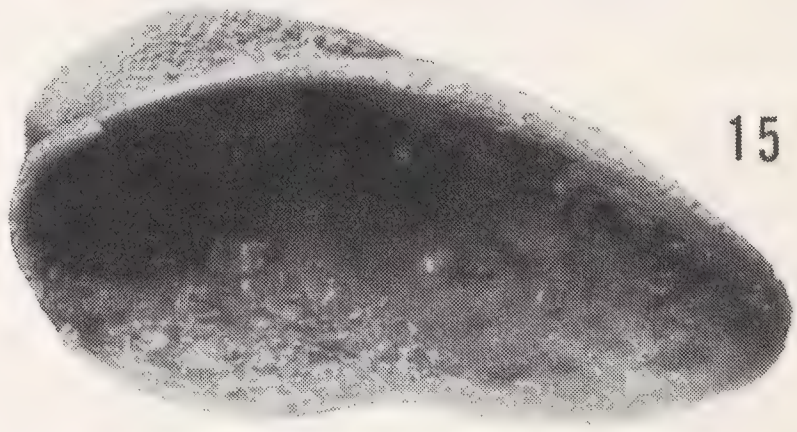
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PLATE 1

Gardner (1926, pl. 15, fig. 4). Dall stated: "The variety, which more abundant material might show to be a distinct species, is stouter, more triangular, with coarser and more nodulous ribs and stronger crenulations of the margin. Alt. 12, max. lat. 7, diam. 6 mm" (of paired valves).

Gardner (1926, p. 58) recognized *curtulus* as a separate species, stating: "This form is certainly distinct from the Ballast Point species which is almost sub-cylindrical in outline and ornamented with a fine and delicate radial threading. The lirae in *grammatus* are double the number of those ornamenting *M. curtulus*, and the fluting of the inner edges is consequently much finer and more feeble."

The type specimen, as figured by Gardner, is incomplete with a portion of the postero-ventral margin broken away, and is larger than any of the more 250 specimens from the type area of the Chipola Formation. Our largest specimen, somewhat similarly incomplete, has a maximum length of 10.5 mm. The average number of coarser ribs is nearer 20 than 15. It also should be noted that the hinge area bears a few small and weak teeth, generally two on the right valve and three on the left.

Subfamily CRENELLINAE
H. and A. Adams, 1857
Genus CRENELLA Brown, 1827

Crenella BROWN, 1827, I11. Conch. Great Britain and Ireland, pl. 31, figs. 12-14.

Stalagmium CONRAD, 1833, Foss. Shells Tert. Formations North Amer., v. 1, no. 4, p. 39 [Oct.].

Myoparo LEA, 1833, Contrib. to Geol. p. 73 [Dec.].

Nuculocardia ORBIGNY, 1842, *in* DE LA SAGRA, Hist. Fis. Pol. Nat. Isla de Cuba; Pt. 2, Hist. Nat., v. 5, Moluscos; Atlas, pl. 27, figs. 56-59 [Text, p. 338, 1847; Spanish Ed.].

Type species, by monotypy, *Mytilus decussatus* Montagu, 1808. Pliocene - Recent, Circumboreal.

CRENELLA MINISCULA Dall
Plate 1, Figures 6, 7

Crenella miniscula DALL, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 803, pl. 35, fig. 22.

Crenella miniscula Dall. GARDNER, 1926, U. S. Geol. Surv., Prof. Paper 142-A, p. 60, pl. 15, fig. 9.

Description: "Shell minute, thin, inflated, elongate ovate, feebly radially striated, the striations apparently diverging from a medial line on the disk; not dichotomous; the beaks smooth; inner margins crenulate; valves nearly equilateral. Alt. 1.75, lat. 1.25, diam. 1 mm.

"This little shell is rare in the marl and resembles in a general way *C. divaricata* Orbigny, of which it is the precursor, but has fainter sculpture and smooth beaks, besides being constantly of smaller size, and is more narrow in form than the young of *C. divaricata* of the same length." (Dall, 1898)

"The smooth prodissoconch can be plainly observed in these minute forms. The affinities of the species are obviously with the later Tertiary or Recent members rather than with the Eocene." (Gardner, 1926)

Holotype: USNM 114624.

Type locality: USGS 2211, Alum Bluff (lower beds), Liberty County, Florida.

Figured specimen: USNM 407804; height 2.9 mm, length 2.0 mm, diameter (left valve) 1.2 mm; locality TU 70, Tenmile Creek, Calhoun County, Florida.

Figured specimen: USNM 407805; height 2.3 mm, length 2.0 mm, diameter (right valve) 0.85 mm; locality TU 549, Chipola River, Calhoun County, Florida.

Discussion: Gardner added the first records of this species from the fauna of the type area of the Chipola Formation, listing it as rare at USGS locality 3419, "McClelland Farm 1 mile below Bailey's Ferry" on the Chipola River and present at locality 7151, Tenmile Creek, Calhoun County, Florida."

Comparison of the more than 700 specimens from 52 Chipola localities in the present collections with numerous specimens from the Recent faunas of the Yucatan Peninsula and the Caribbean Sea area leads the writer to believe that Dall's specimen from the lower bed at Alum Bluff may have been rather worn, for the costae on our specimens are somewhat broader and stronger than on *Crenella divaricata*. The shape is almost equally variable in the two species.

The largest specimen in the collection, a worn valve from TU 655, on Tenmile Creek, has a height of 3.3 mm, and a length of 2.4 mm.

Genus MUSCULUS Röding, 1798

Musculus RÖDING, 1798, Mus. Bolten., pt. 2, p.

156 [not preoccupied by *Musculus* Martyn, 1787, a non-binomial work].

Modiolaria BECK *in* ROBERT, (?) 1838, Zool. Voy. Recherche en Islande et en Grönlande, pl. 17, figs. 1-4.

"*Lanistes* Humph." SWAINSON, 1840, Treat. Malac., p. 385 [*non* Montfort, 1810 (Gastr.)].

Modiolarca GRAY, 1840, Synop. Cont. Brit. Mus., ed. 42, p. 151 [err. pro *Modiolaria, fide* Sherborn, 1928, Index Anim., p. 4122; however, Gray, 1847, Proc. Zool. Soc. London, v. 15, p. 199, lists type as *Modiola trapezina*].

Lanistaina GRAY, 1847, Zool. Soc. London, Proc., v. 15, p. 199 [n. n. pro "*Lanistes* Swainson, 1840; not Montf." + *Modiolaria* 'Beck' Loven, 1846;" *Mytilus discors* cited as type species.]

Type species, by subsequent designation, Iredale, 1915, *Mytilus discors* Linnaeus, 1767. Recent, Circumboreal.

Subgenus RYENELLA Fleming, 1959

Ryenella FLEMING, 1959, Royal Soc. New Zealand, Trans., v. 87, p. 172.

Type species, by original designation, *Mytilus impactus* Hermann, 1782. Lower Miocene to Recent, New Zealand.

Discussion: As pointed out by Fleming in his original description of *Ryenella*, quoting Soot-Ryen, 1955 (p. 73), "*M. impactus* Hermann and similar species . . . 'are more inflated than the typical *Musculus*, and the arrangement of the retractor muscles is quite different . . . the posterior retractors have a strong, elongated branch fastened along the dorsal margin and a single slender branch fastened above the posterior adductor. Whereas in *Musculus* they are continuous and united with the posterior adductor."

MUSCULUS (RYENELLA) LATERALIS PRAELATERALIS H. E. Vokes, n. subsp.
Plate 1, Figures 10, 11

Modiolaria sp. indet., DALL, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 806.

Modiolaria sp., GARDNER, 1926, U. S. Geol. Surv., Prof. Paper 142-A, p. 59.

Description: Shell elongately sub-ovate, moderately inflated with broad, rounded posterior-ventral umbonal ridge; prosogyrate somewhat flattened umbones, terminating just posterior to dorsal side of rounded anterior end of valve; ventral margin slightly convex, ventral half of posterior end broadly rounded with dorsal half forming posterior portion of a broadly arched dorsal margin; anterior and posterior thirds of ventral portion of valve surface radially costate with median area smooth except for growth lamellae, and in most specimens delimited from the costate areas by a rounded sulcus; radial ribs on anterior third and on the ventral half to two-thirds of the posterior area relatively broad and flat-topped with slightly narrower inter-rib areas marked by lamellose crossbars forming a latticed sculpture, the width of the inter-rib area decreasing dorsally on posterior segment until they lose the crossbar sculpture and become linear grooves between the narrowed ribs along the dorsal portion; 15 to 18 ribs present on anterior segment and 40 to 50 on the postero-dorsal one. Inner margin of valves crenate at rib terminations, median area smooth. Hinge area lacking teeth.

Holotype: USNM 407806; length 10.0 mm, height 6.0 mm, diameter (left valve) *ca.* 2.8 mm. Type locality: TU 825, Farley Creek, Calhoun County, Florida.

Paratype: USNM 407807; length 5.8 mm, height 4.1 mm, diameter (right valve) *ca.* 1.1. mm; locality TU 196, Tenmile Creek, Calhoun County, Florida.

Discussion: Dall (1898b, p. 806) reported the presence of a single broken valve representing "a species similar to *M[odiolaria] lateralis* Say, but marked especially by well-developed latticed sculpture in the interspaces of the radii." Gardner (1926, p. 59) cites the locality as USGS 2564 (= TU 457) and adds that "no further material has been collected which might serve to identify this species."

The present collections contain some 190+ specimens from 43 localities in the Chipola River area, all marked by this characteristic ornamentation. In a few of the small specimens, including the figured paratype, the cross-lamellae extend in some areas over the rib tops as well as in the interspaces. However, the Tulane University collections contain a large specimen of the Recent *M. lateralis* (Say) (1822, p. 264) from off Longboat Key, western Florida, that shows similar cross-lamellae in the intercostal areas near the postero-ventral margin; none of the smaller forms in our Recent collections reveal this feature. The Chipola species also seem to have more numerous radial costae in both the anterior and posterior area than are to be found in the Recent specimens. The similarities in shape and in general features, including the nature of the infra-specific variation present in the two forms, however, strongly suggests that the Chipola species is the early Miocene ances-

tor of the Pliocene (?) to Recent *M. lateralis* (Say).

The species described by Gabb (1881, p. 377, pl. 47, fig. 81) as *Crenella (Modiolaria) translucida* "from the Pliocene Clay Beds between Limon and Moen, Costa Rica" is, as noted by Dall, (1898b, p. 807) "a very similar species" to *M. lateralis*. As compared with our Chipola form, it is relatively narrower with a straighter ventral margin. The dorsal margin, behind the umbone is broadly arched trending into the more sharply rounded postero-ventral end, and insofar as can be determined from the illustration, the anterior radials are broader and less numerous.

Musculus praelateralis is, as mentioned above, represented in the Tulane collections by more than 190 valves. These come from 43 localities extending stratigraphically from the base to the uppermost beds in the exposed sections: 15 of the localities represented are from the banks of the Chipola River, 14 are from along Tenmile Creek, west of the river, and 14 are from Farley Creek, flowing into the river from the east.

Subgenus PLANIMODIOLA Cossmann, 1887

Planimodiola COSSMANN, 1887, Cat. Illus. Coquilles Foss. Eocene Envir. Paris, fasc. 2, p. 159.

Type-species, by original designation, *Modiola sulcata* Lamarck, 1805. Middle Eocene, Paris Basin, France.

Discussion: Lamarck (1805, p. 123) described *Modiola sulcata*: "Modiola oblongo-spathulata; margine inferiore arcuto, carinato; sulcis transversis diversis." In his discussion he noted that "Cette espèce est remarkable par sa forme . . . oblongue, presque en forme de spatule," with the ornamentation similar to that of "*mytilus discors*, Lin." The species was not illustrated until 1807 (pl. 17, figs. 11a, 11b).

In his description of *Planimodiola* Cossmann noted that the shells are "ovale, aplatie, atténuée en avant, élargie en arrière, caractérisée par deux sinuosités qui limitent, sur le contour antérieur, les extrémites de l'aire dépourvue de côtes rayonnantes; cette aire est largement développée et généralement couverte d'un fin treillis de stries rayonnantes et concentriques; bord antérieur et bord ligamentaire bien crénelés."

Although often considered as being a synonym of *Musculus*, *Planimodiola* is distinguished by its more elongate, less inflated valves with more pronounced and sharply rounded anterior extremities.

PLATE 2

Figures Page

1-4. *Lithophaga antillarum* (Orbigny). 168

1, 2. Figured specimen, USNM 407811 (X 1); length 74.0 mm, height 23.7 mm (fig. 1, lateral view; fig. 2, dorsal view of paired valves).
Locality: TU 1048, Farley Creek.

3. Figured specimen, USNM 407812 (X 1.5); incomplete valve. View showing complex ornament on posterior area of valve.
Locality: TU 1048, Farley Creek.

4. Figured specimen (X 1.5); view of posterior area of incomplete valve of Recent specimen; compare with fig. 3.
Locality: TU R-109, northern Panamá.

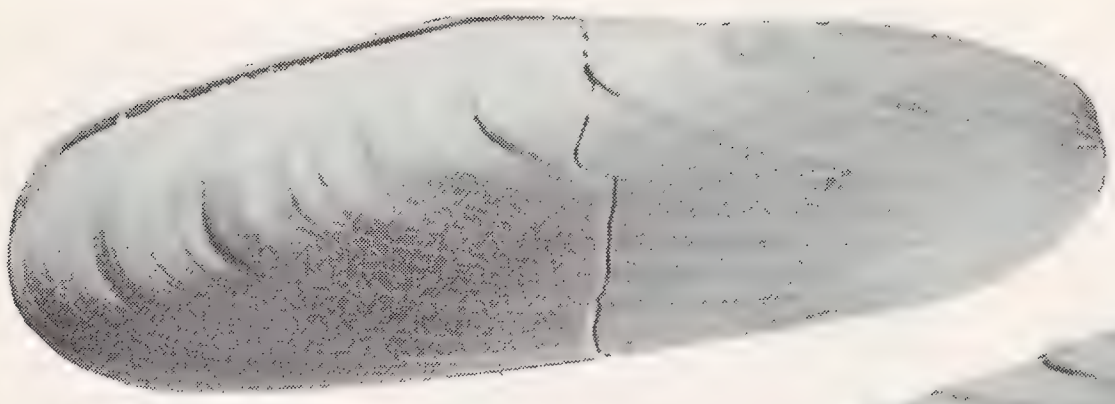
5, 6. *Lithophaga (Diberus) bisulcata* (Orbigny). 170

5. Figured specimen, USNM 407814 (X 1.5); length 28.6 mm, height 11.7 mm.
Locality: TU 1196, Farley Creek.

6. Figured specimen, USNM 407815 (X 1.5); length 24.0 mm, height 9.2 mm.
Locality: TU 1196, Farley Creek.

7. *Modiolus ducatelli* (Conrad) 171

Figured specimen, USNM 407816 (X 1); length 90.0 mm, height 59.8 mm.
Locality: TU 1196, Farley Creek.



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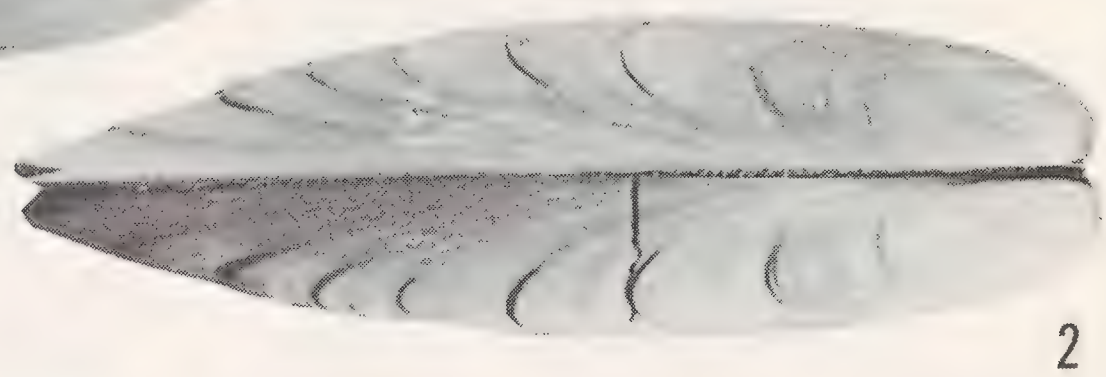

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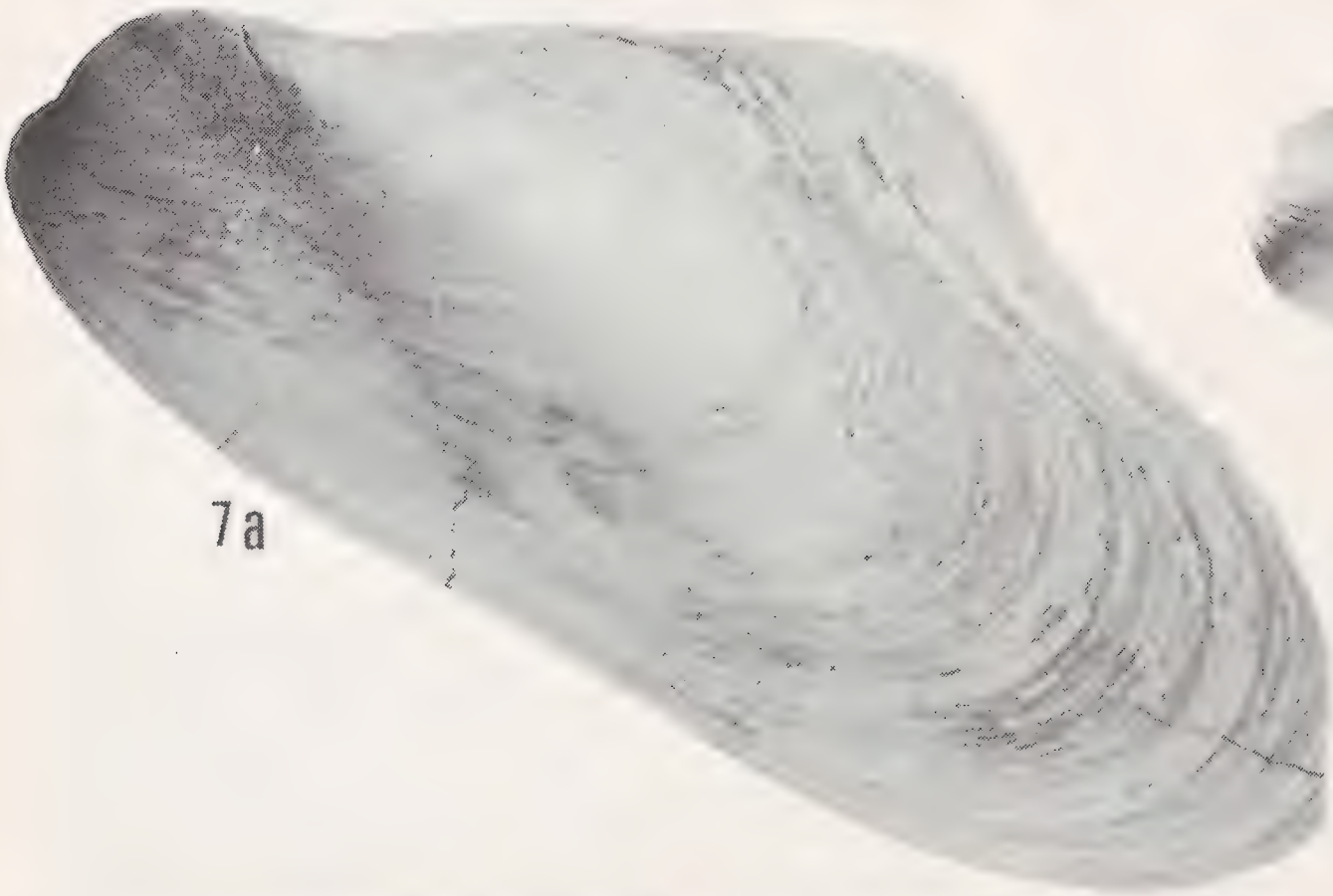

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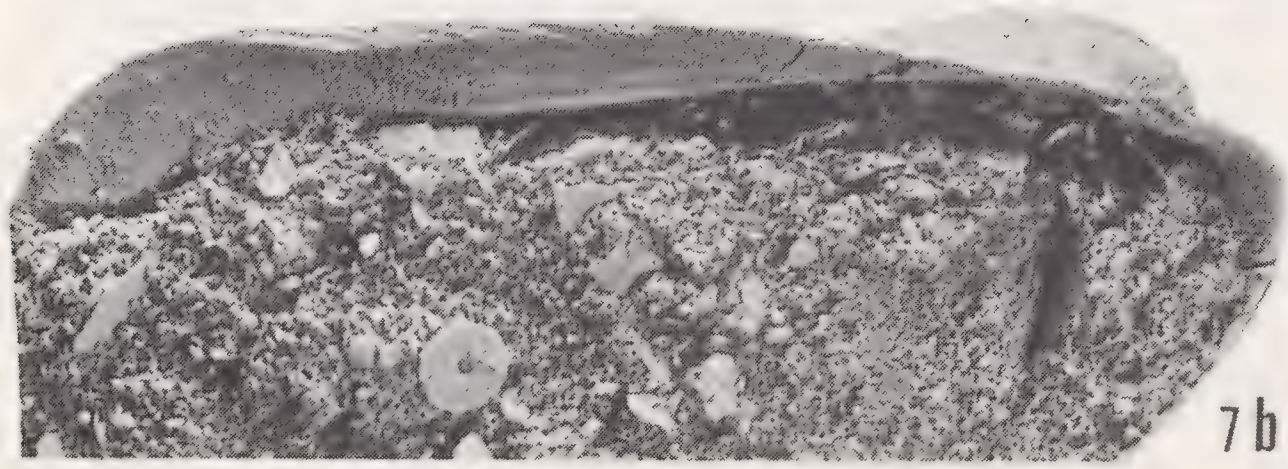

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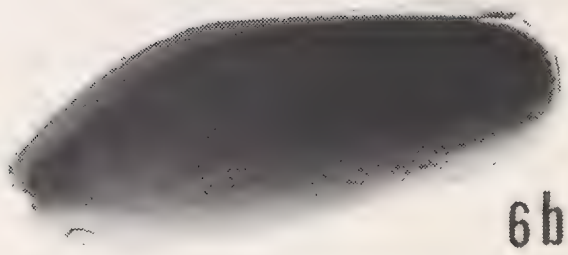

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PLATE 2

MUSCULUS (PLANIMODIOLA) DISINFLATUS
H. E. Vokes, n. sp.
Plate 1, Figures 8, 9

Description: Shell relatively small, elongate-ovate with greatest height slightly posterior to mid-length of valves; low, prosogyrate umbones near anterior end, which is slightly produced and broadly rounded; dorsal margin arched, passing into the broadly rounded posterior end; ventral margin almost straight with, however, a weak convexity along the margin of the median, non-ribbed area; anterior and posterior portions of valve surface radially ribbed with eight to ten ribs on the anterior area, the more posterior of these being broad and flat-topped with slightly convexly-bottomed interspaces of approximately equal width, both ribs and interspaces narrowing towards the umbone; the ventral termination of the four or five posteriorly convex interspaces tending to project as rounded areas crenulating the shell margin; posterior area with 26 to 30 wide, flat-topped ribs separated by relatively narrow grooves, the more ventrally situation costae tending to be almost twice the width of those toward the dorsal portion of the valve surface; median, non-ribbed area forming approximately two-thirds of the ventral margin, delimited from the ribbed areas by very shallow grooves, its surface marked only by occasional growth lamellae; valve margins slightly crenulated by terminations of ribs except at the posterior part of the anterior area as noted above; ligamental area smooth, but with relatively strong, tooth-like crenulae immediately below the umbone and on the dorsal slope posterior to the ligament.

Holotype: USNM 407813; length 6.6. mm, height 3.4 mm, diameter (paired valves) 2.4 mm. Type locality: TU 458, Chipola River, Calhoun County, Florida.

Discussion: The writer is aware of no similar weakly inflated spatulate species of *Musculus* that has been reported from the Western Hemisphere faunas, fossil or Recent. "*Modiolus*" *dalli* Glenn *in* Clark *et al.*, (1904, p. 367, pl. 97, figs. 9. 10) from the Choptank Formation of Maryland appears to be most closely approximate in degree of inflation of valves, but differs in being proportionately higher relative to valve length, in having a relatively longer, straight dorsal margin with subangulate bend at posterior end, and in apparently lacking the tooth-like crenulations below the umbone and on the dorsal surface posterior to the ligamental area. Judging from the illustrations it appears that the radial costae are narrower and much more numerous on the posterior area than in the present species.

Musculus disinflatus, n. sp., is represented in the Tulane University collections from the Chipola Formation by 79 valves from 19 localities. The largest valve has a length of 8.1 mm.

Genus GREGARIELLA Monterosato, 1884

Gregariella MONTEROSATO, 1884, Nomen. Gen. Spec. Conch. Mediterranee, p. 11.
Botulina DALL, 1889, U. S. Natl. Mus., Bull. 37, p. 38.
Tibialectus IREDALE, 1939, Gt. Barrier Reef Exped., 1928-9; Moll. I; Sci. Repts., v. 5, no. 6, p. 424.

Type species, by subsequent designation, Crosse, 1885, *Modiolus sulcatus* Risso, 1826 (*non* Lamarck, 1805, nor 1819) = *Modiolus barbatellus* Cantraine, 1835, = *Modiolus opifex* Say, 1825. Recent, Mediterranean Sea.

Discussion: This genus of mytiloids is known to bore into thick-shelled molluscs (Carpenter [1857, p. 124] cites borings in *Spondylus calcifer* and *Murex regius*), rocks (Olsson, 1961, p. 129), and corals (present collections).

GREGARIELLA ARCAFORMA
H. E. Vokes, n. sp.
Plate 1, Figures 14, 15

Description: Shell small, convex, modioliform almost *Arca*-like in general shape with subterminal prosogyrate umbones marked by a broad median sulcus extending to middle of ventral margin; well-rounded anterior margin passing into the ventral one, which is made broadly concave by the umbonal sulcus; posterior end narrowly rounded, almost pointed on ventral portion, then trending anteriorly in a slightly convex, almost straight slope to the broadly angled junction with the relatively straight dorsal margin; surface of anterior end with a few microscopic radial ribs, medial surface smooth up to posterior side of umbonal sulcus, beyond which it is ornamented by fine, rounded radials descending from the crest at posterior side of median inflation and terminating in a descending row at edge of median sulcus; posterior and posterio-dorsal surface with stronger divaricating radials often nodose when crossed by rounded concentric growth lamellae; inner margin crenulated by radial ribbing, the crenulae on the anterior end and the posterior portion of ventral margin finer and less conspicuous than those on posterior area and posterior side of dorsal margin beyond the narrow, linear resilifer, but continuing as weak projections dorsal

to that structure; muscle scars not visible.

Holotype: USNM 407810; length 9.9 mm, height 4.9 mm, diameter (paired valves) *ca.* 4.5 mm. Type locality: TU 1196, Farley Creek, Calhoun County, Florida.

Discussion: Gregariella arcaforma is, in most respects, similar to *G. coarctata* (Carpenter) (1857, p. 123, sp. 172), a Recent Pacific species ranging from Baja California to Ecuador and the Galápagos Islands. The latter species, however, attains a much larger size; Olsson (1961, p. 129) cites a specimen from Manta, Ecuador as "length 28 mm; height 11 mm; diameter 10.8 mm." The largest Chipola specimen has a length of 10.9 mm. In addition, the posterior extremity of *G. coarctata* is rounded rather than almost pointed as in *G. arcaforma*, the radial ribbing toward the anterior end is somewhat stronger, and the ribs more numerous than in our species.

The Recent western Atlantic species *Gregariella coralliophaga* (Gmelin)(1791, p. 3359) is also a larger form, attaining lengths in excess of 25 mm. It also has a more gently sloping dorsal margin, with the radials on that area less strongly developed and proportionately more abundant than in the present Chipola forms. It seems quite probable, however that the latter is ancestral to the Recent species.

The form from the Tampa Limestone at Ballast Point, Florida, described by Dall as *Modiolus (Gregariella) minimus* (1898b, p. 797, pl. 35, fig. 26), was based upon "a siliceous pseudomorph, retaining but little of the external surface." Mansfield (1937, p. 220) states that "only a silicified fragment of the original shell is preserved on one beak of the holotype." This fragment is not visible on Dall's inadequate illustration of the dorsal surface of the pseudomorph. Although Dall's measurements of the type - "Alt. 8, lat. 3.5, diam. 4 mm" - are comparable with those of most specimens of the present species, it is not possible to make any comparison of the two forms.

Present Tulane University collections contain valves of *Gregariella arcaforma* from seven localities.

Subfamily LITHOPHAGINAE H. and A. Adams, 1857

Genus LITHOPHAGA Röding, 1798

Lithophaga RÖDING, 1798, Mus. Bolten., pt. 2, p. 156.
Lithophagus MEGERLE, 1811, Ges. Nat. Fr. Berlin, Mag., v. 5, p. 69.
Lithodomus CUVIER, 1817, Le Regne Animal, v. 2, p. 471.
Lithodoma BLAINVILLE, 1823, Dict. Sci. Nat., v. 27, p. 66.

Type species, by monotypy, *Lithophaga mytuloides* Röding = *Mytilus lithophagus* Linnaeus. Recent, Mediterranean Sea.

LITHOPHAGA ANTILLARUM (Orbigny) Plate 2, Figures 1-4

Lithodomus antillarum ORBIGNY, 1842, *in* DE LA SAGRA, Hist. Fis. Pol. Nat. Isla de Cuba; Pt. 2, Hist. Nat., v. 5, Moluscos; Atlas, pl. 28, figs. 12, 13 [Text, p. 351, 1847; Spanish Ed.].
Modiola corrugata PHILLIPI, 1846, Abbild. und Beschreib. Conchyl., v. 2, p. 147, pl. 1, fig. 1.
Lithodomus straminius DUNKER *in* REEVE, 1858, Conch. Icon, v. 10, *Lithodomus*, pl. 2, fig. 11.
Lithophaga dactylus Sowerby. MÖRCH, 1853, Cat. Conch. Yoldi, pt. 2, p. 55 [not of Sowerby, 1824].
Lithophagus caribaeus Philippi. DALL, 1889, U. S. Natl. Mus., Bull. 37, p. 38 [not of Philippi, 1847].
Lithophaga straminea (Reeve). DUNKER, 1882, Conchylien-Cabinet, ser. 2, v. 8, pl. 2, figs. 1, 2.
Lithophaga antillarum (Orbigny). DALL, 1898, Wagner Free Inst. Sci., Trans., v. 23, pt. 4, p. 799.
Lithophaga (Lithophaga) antillarum (Orbigny). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (Mid. Amer. Res. Inst., Publ. 54), p. 36, pl. 34, fig. 7.

Description: "*Lithodomus* testa elongata, recta, epidermide fuscescente; latere buccali angustato, obtuso; latere anali dilatato; subacuminato; regione palleali ligamentique transversim striata; latere anali (adulto) striis divaricatis ornato, intus iridescente; latere anali tenue.

"Dimension. Longitud . . . 70 millim . . . 3 polgadas."

"Esta especie es mayor que la anterior y mas prolongada; tambien se distingue por su color bermejo y por las estrias trasversales que cubren en la juventud los dos lados de la concha, dejando en medio una parte lisa, las cuales se vuelven divergentes en la edad adulta. Es propia de Cuba, la Martinica y la Guadalupe." (Orbigny, 1847)

Figured specimen: USNM 407811; length 74.0 mm, height 23.7 mm, diameter (paired valves)

21.5 mm; locality TU 1048, Farley Creek, Calhoun County, Florida.

Figured specimen: USNM 407812; length (incomplete) 50.7 mm, height (of fragment) 24.4 mm; locality TU 1048, Farley Creek, Calhoun County, Florida.

Discussion: *Lithophaga antillarum* may be distinguished from *L. nigra* (Orbigny) (1842, pl. 28, figs. 10, 11), the only other Recent species of *Lithophaga* s.s. in the warmer waters of the western Atlantic Ocean, by its lighter color and by the fact that the posterior area of the valves is marked by a pattern of irregularly radiating or chevron-shaped lirations or rows of low nodes, formed by the lateral extension of the transverse lirae that are present on the more anterior part of the valves. The Chipola specimen here figured (pl. 2, fig. 3) is the most complexly patterned valve that the present writer has observed, although it is closely approximated by one from the sub-Recent of the northern coast of Panamá (pl. 2, fig. 4).

The form described by Gardner (1926, p. 60, pl. 15, fig. 10) as *Lithophaga oryzoides*, with the type from the Alum Bluff Group at Oak Grove on the Yellow River in Okaloosa County, Florida, and said to be present also in beds of Chipola age at Boynton Landing on the Choctawhatchee River, Washington County, although compared to "*L. niger* D'Orbigny," clearly is not to be referred to *Lithophaga* s.s. The essentially modioliform shape with narrowed posterior end suggests that, if it is indeed a *Lithophaga*, it might represent a form similar to *L. (Myoforceps) aristata* Dillwyn, in which the secondary posterior shelly prolongations have been lost during fossilization.

Lithophaga antillarum is not common in the Chipola collections, the specimen here figured being the only relatively complete one with paired valves. A second rather fragmented pair, plus one almost complete valve and numerous fragments, representing four localities, are present in the Tulane University collection.

Subgenus DIBERUS Dall, 1898

Diberus DALL, 1898, Wagner Free Inst. Sci., Trans., v. 3, p. 4, p. 799.

Type species, by original designation, *Lithophaga plumula* (Hanley, 1843) (as *Modiola*). Recent, Gulf of California to Peru.

LITHOPHAGA (DIBERUS) BISULCATA (Orbigny)

Plate 2, Figures 5, 6

Lithodomus bisulcatus ORBIGNY, 1842, *in* DE LA SAGRA, Hist. Fis. Pol. Nat. Isla de Cuba; Pt. 2, Hist. Nat., v. 5, Moluscos; Atlas, pl. 28, figs. 14-16 [Text, p. 352, 1847; Spanish Ed.]

Modiola appendiculata PHILIPPI, 1846, Abbild. und Beschreib. Conchyl., v. 2, p. 150, pl. 1, fig. 4.

Lithophaga appendiculata Philippi. MÖRCH, 1853, Cat. Conch. Yoldi, pt. 2, p. 56.

Lithodomus biexcavatus REEVE, 1857, Conch. Icon., v. 10, *Lithodomus*, pl. 4, figs. 22a, b.

Lithophaga (Diberus) bisulcata (Orbigny). DALL, 1898, Wagner Free Inst. Sci., Trans., v. 3, pt. 4, p. 801.

Lithophaga (Diberus) bisulcata (Orbigny). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (Mid. Amer. Res. Inst., Publ. 54), p. 36, pl. 34, fig. 9.

Description: "*Lithodomus* testa elongata, sublanceolata, laevigata, epidermide fusca; latere buccali brevi; latere anali elongato, producto, oblique truncato, externe calcareo induto, radiatim bisulcato; apice bilamellato.

"Dimension. Longitud . . . 20 millim . . . 11 lineas.

"Esta concha es vecina del *L. caudigerus* de la costa africana, y se distingue por el encostramiento esterior formado dos surcos profundos que parten del vértice y van á la region anal, donde dejan en medio una lámina prolongada mucho mas allá de la concha. Se halla en Cuba, la Jamaica, la Martinica, la Guadalupe y Santo Domingo." (Orbigny, 1847)

Figured specimen: USNM 407814; length 28.6 mm, height 11.7 mm, diameter (left valve) 5.9 mm; locality TU 1196, Farley Creek, Calhoun County, Florida.

Figured specimen: USNM 407815; length 24.0 mm, height 9.2 mm, diameter (left valve) 4.1 mm; locality TU 1196, Farley Creek, Calhoun County, Florida.

Discussion: As noted by Orbigny, it is the external incrustation that forms the two deep sulcations, which extend from the umbone to the posterior margin. Examination of Recent specimens show that the incrustration is exceptionally thick in the area between the two sulci and that its almost vertical lateral sides serve to emphasize the bisulcate appearance. When the incrustation is removed, as in the fossil specimens where it is not preserved, the sulci on the valve surface are broad and shallow and not very obvious.

Lithophaga (Diberus) bisulcata is not rare in the collections from the Chipola Formation, being represented by 106

specimens, of which 14 are paired valves. These come from seven localities, at all of which corals are present.

The form from Preston Sink, Alachua County, Florida, described by Gardner (1936, p. 14, pl. 8, figs. 5-7) as *Lithophaga cookei* from the "Hawthorn formation? of the Alum Bluff group," differs from the present species in that the outline of the holotype mold has the greatest height toward the anterior end rather than at a point transverse to the postero-dorsal angulation.

Subfamily MODIOLINAE Keen, 1958
Genus MODIOLUS Lamarck, 1799 [ICZN Op. 325]

Volsella SCOPOLI, 1777, Introd. Hist. Nat., p. 397 [suppressed, ICZN Op. 325].
Modiolus LAMARCK 1799, Mém. Soc. Hist. Nat. Paris, v. 1, p. 87.
Modiola LAMARCK, 1801, Syst. Anim. sans Vertèbr., p. 113.
Perna "Adanson" H. and A. ADAMS, 1858, Gen. Recent Moll., v. 2, p. 515.
Eumodiolus IHERING, 1900, Malac. Soc. London, Proc., v. 4, p. 87.

Type species, by tautonomy, *Mytilus modiolus* Linnaeus, 1758. Recent, Circumboreal, southward to Bay of Biscay and Cape Hatteras in Atlantic Ocean and ? to Baja California and Japan in the Pacific Ocean.

MODIOLUS DUCATELII (Conrad, 1840)
Plate 2, Figure 7

Modiola Ducatellii CONRAD, 1840, Foss. Medial Tertiary United States, no. 2, p. 53, pl. 28, fig. 2.

Description: "Shell profoundly elongated, ventricose, valves contracted obliquely from the apex to the middle of the basal margin; lines of growth coarse and prominent; extremity of hinge line salient and rounded; posterior extremity regularly rounded; anterior extremity rather prominent and pointed.

"*Locality*. Cliffs of Calvert, Md. Professor Ducatel." (Conrad, 1840)

Figured specimen: USNM 407816; length 90.0 mm, height 59.8 mm, diameter (left valve) 15.6 mm; locality TU 1196, Farley Creek, Calhoun County, Florida.

Discussion: According to Glenn (*in* Clark *et al.*, 1904, p. 366), this species is known from the Calvert, Choptank and St. Mary's formations. Although Conrad cited the specific name as for "Professor Ducatel," at that time State Geologist of Maryland, his original spelling included two "l"s in the name of the species, and also earlier for his *Venus Ducatelli*" (1838, [1840] pt. 1, p. 8, pl. 4, fig. 2). As far as the writer is aware, the earliest emendation to a single "l" was that of Dall, 1893, in his Republication of the Conrad work where, in the "Explanation of the Plates" (p. 118-129), he added to the explanation of plate 4, figure 2 (p. 118) and plate 28, figure 2 (p. 123), respectively, that the name "should be *Ducateli*" and "should be written *Ducatelii*."

In 1898b (p. 793) Dall listed four species of *Modiolus* from the Tertiary of the eastern United States, as the only "valid species belonging to the section *Modiolus* as restricted . . . except *M. tulipus* Lam., which occurs in the later rocks of the West Indies." The four species were, in addition to *M. ducatelii: M. silicatus* Dall, 1898b (p. 793, pl. 27, fig 28, where it is identified as *M. tampaensis* Dall), from the "Upper Oligocene silex beds at Ballast Point, Tampa Bay, Florida" (now considered to be of Early Miocene age); *Modiolus inflatus* (Tuomey and Holmes) (1857, p. 33, pl. 14, fig. 3), from the Miocene of New Jersey and Pliocene of South Carolina; and *Modiola gigas* Wagner *in* Dall (1898a, p. 10, pl. 2, fig. 3A, B), ?Pliocene, Yorktown, Virginia (see Olsson, 1914, p. 13).

Modiolus ducatelii is represented in the Tulane University Chipola collections by many valves, mostly incomplete. The one figured here is the most perfect in the collection but fragments, especially from TU 555 on the Chipola River, indicate that the species attains dimensions at least one-third larger in overall size, and reveal a tendency for a progressively greater prolongation of the posterior extremity relative to the increase in size of other parts of the valve. Younger specimens with a shorter posterior agree so very closely with the figure of a specimen from the Lower Miocene of New Jersey, identified by Whitfield (1984, p. 39, pl. 6, fig. 3) as "*Modiola inflata*" [=*Mytilus inflatus* Tuomey and Holmes, (1857, p. 33, pl. 14, fig. 3; "Pleiocene," South Carolina)] that the writer is inclined to believe these Early Miocene forms represent the present Conrad species.

In addition to the specimens here definitely identified as *M. ducatelii*, the Tulane collections contain many small

modiolid-like forms that are essentially subtriangular in outline but lack all trace of any posterior prolongation. The largest complete specimen has a length of 6.1 mm and a height of approximately 3.9 mm. These are considered as representing young, possibly newly hatched specimens of *M. ducatelii*, especially since valves up to 30 mm in length that are associated with typical adult forms of that species similarly show no trace of the posterior prolongation. The smallest specimen upon which such a trend can be observed has a length of approximately 33 mm, unfortunately the anterior end of this valve has been broken so that no precise measurement can be made.

Genus BOTULA Mörch, 1853

Botula MÖRCH, 1853, Cat. Conch. Yoldi, pt. 2, p. 55.

Type species, by subsequent designation, Dall, Bartsch and Rehder, 1938, *Mytilus fuscus* Gmelin. Recent, North Carolina and Bermuda, southward to north of Rio de Janeiro, Brazil.

Discussion: Modiolus cinnamomeus Lamarck, designated as type species by Dall, 1898b (p. 792) was cited by Mörch as "*Modiola cinnamomea* var. Lam." in the synonymy of *Botula fusca*; hence *M. cinnamomea* s.s. is not an available species.

BOTULA FUSCA (Gmelin)
Plate 1, Figures 12, 13

Mytilus fuscus GMELIN, 1791, Systema Naturae, ed. 13, v. 1, pt. 6, p. 3359.

Modiolus (Botula) cinnamomeus Lamarck. DALL, 1889, U. S. Natl. Mus., Bull. 37, p. 38 [*B. cinnamomea* is now known to be an Indo-Pacific species].

Botula fusca (Gmelin). VOKES and VOKES, 1983, Mesoamer. Ecol. Inst., Mon. 1 (Mid. Amer. Res. Inst., Publ. 54), p. 36, pl. 34, fig. 11.

Description: Shell moderately small, inflated, oblong, arcuate, with arched dorsal margin and concave ventral one; enrolled umbones at upper anterior extremity of valve in front of rounded anterior margin; posterior margin relatively wide and rounded; shell surface usually marked by prominent concentric ridges formed during growth rest periods, otherwise smooth; hinge edentulous, ligament long, narrow.

Figured specimen: USNM 407808; length 10.1 mm, height 8.2 mm, diameter (left valve) 4.4 mm; locality TU 547, Chipola River, Calhoun County, Florida.

Figured specimen: USNM 407809; length 26.0 mm, height 12.8 mm, diameter (left valve) 7.4 mm; locality TU 1048, Farley Creek, Calhoun County, Florida.

Discussion: This species is rare in the Chipola fauna, being represented in the Tulane collections by five incomplete paired valve specimens and one single valve from TU 547, a coral reef locality on the Chipola River, one paired valve form from the Chattahootchee/Chipola contact on Tenmile Creek at TU 830, and one valve from TU 1048 on Farley Creek, a locality marked by numerus heads of *Porites* and *Stylopora*, together with numerous *Antillophyllia chipolana* Weisbord.

Gardner (1926, p. 59) cited "a single battered valve" that she identified as "? *Modiolus (Botula) cinnamomeus* Lamarck" from locality 2213, one mile [=*ca.* one-half mile] below Baileys Ferry, on the Chipola River. This specimen is presumed to be the basis of Dall's (1898b, p. 797) record of the occurrence of "*Modiolus cinnamomeus*" in the "Chipola marl Chipola River."

IV. LOCALITY DATA

The following Tulane University locality numbers are all in the Chipola Formation, Calhoun County, Florida.

70. Tenmile Creek, at bridge of Florida Highway 73 (NW 1/4 Sec. 12, T1N, R10W).
196. Tenmile Creek, about 1/4 mile upstream from bridge of Florida Highway 73 (NE 1/4 Sec. 11, T1N, R10W).
457. West bank of Chipola River, about 1/2 mile below Tenmile Creek (SW 1/4 Sec. 17, T1N, R9W) (same as USGS 2213, 2564, and 3419, "One mile below Bailey's ferry").
458. East bank of Chipola River, above Farley Creek (SW 1/4 Sec. 20, T1N, R9W).
459. East bank of Chipola River, steep bank about 1,500 feet above the mouth of Taylor Lake Branch (NW 1/4 Sec. 29, T1N, R9W).
547. West bank of Chipola River, about 2,000 feet above Fourmile Creek (SW 1/4 Sec. 29, T1N, R9W).
548. West bank of Chipola River, at bend about 1,800 feet south of mouth of Farley Creek (NW 1/4 Sec. 29, T1N, R9W).
549. East bank of Chipola River, about 1/4 mile below Fourmile Creek (NE 1/4 Sec. 32, T1N, R9W).

555. East bank of Chipola River, about 1,000 feet above Fourmile Creek (SW 1/4 Sec. 29, T1N, R9W).
655. Tenmile Creek, about 0.1 mile downstream from bridge on Florida Highway 73 (NW 1/4 Sec. 12, T1N, R10W).
825. Farley Creek at abandoned mill about 1/4 mile west of bridge on Florida Highway 275 (SW 1/4 Sec. 21, T1N, R9W).
830. Tenmile Creek, at powerline crossing about one mile west of Chipola River (SE 1/4 Sec. 12, T1N, R10W).
1048. Farley Creek, south bank, about 0.8 miles east of bridge on Florida Highway 275 (NE 1/4 Sec. 21, T1N, R9W).
1196. Farley Creek, north bank about 0.8 mile east of bridge on Florida Highway 275 (NE 1/4 Sec. 21, T1N, R9W).

The following is a Recent Tulane locality number.

R-109. Fill for refinery at Bahia las Minas, Isla Payardi, Prov. of Colon, Panamá (radiocarbon dated at 7,000 y.b.p.).

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AN UNUSUAL DISTORTED *SPONDYLUS* FROM THE MOÍN FORMATION (PLEISTOCENE), COSTA RICA

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A single left valve of a much distorted specimen of *Spondylus bostrychites* Guppy (1867, p. 176) was collected from Tulane locality 953 at Moin Hill, the type locality of the Moín Formation (Gabb, 1895, p. 80) considered to be of early Pleistocene age (Akers, 1972, pp. 42-44, fig. 3).

The valve under consideration appears to have attained essentially a normal adult size and ornamentation, with a height of 115 mm, a width of 107.3 mm, and a diameter of 36.5 mm. Then the anterior margin began to trend inwards with coarsely rugose, non-ornamented growth increments accumulating diagonally to margin an increasingly smaller valve opening. Prior to the onset of distortion the inner margin had a width of about 100 mm; this was reduced to 66 mm. The marginal distortion appears essentially to have been confined to the anterior side and to have tended to tilt the left valve relative to its original normal position. This is evidenced by the fact that the rugose increments progressively overlap posteriorly around the valve margin such that the area of distorted growth gradually passes from a width of about 32 mm on the anterior side to being essentially absent just below the posterior end of the hinge area.

That this same distortion affected the hinge area is evidenced by the greater width of its anterior portion and by the fact that the resilial pit tends to develop a slight posteriorly trending curve in its later stages.

The right valve was not found and its condition is unknown. It seems probable,

however, that it must have developed a similar distortion as the inter-valve marginal area became progressively narrower. The reason for this distorted growth is not evident; the outer surface of the valve shows no evidence of any damage. It may be that the right valve was the one damaged; the fact that the anterior margin of the distorted segment is relatively straight, rather than rounded, and that the entire margin is irregularly undulating, not smooth, is indicative of extreme distortion in that valve also.

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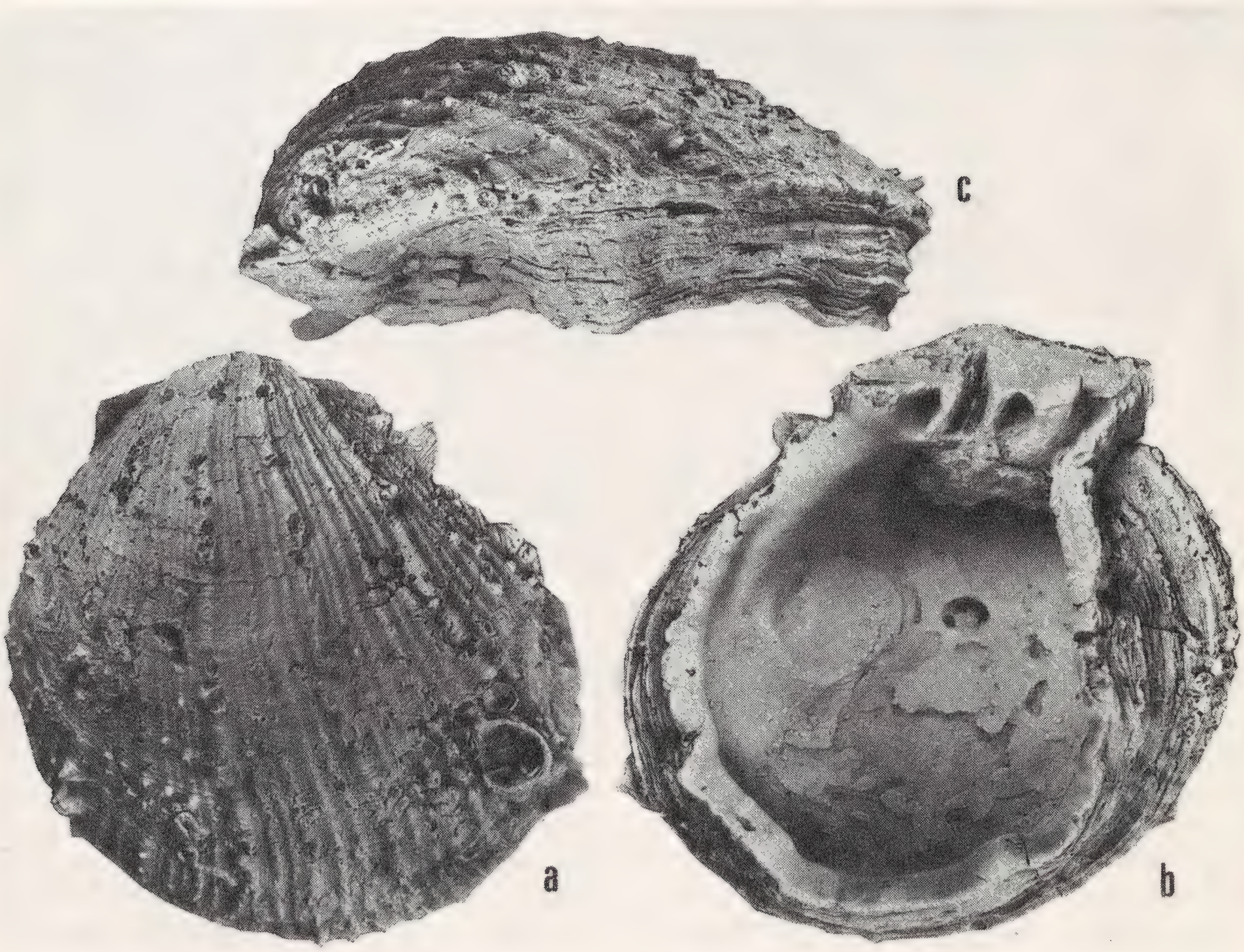
December 15, 1986



Text figure 1, *Spondylus bostrychites* Guppy; height 115.0 mm, width 107.3 mm, diameter 48.0 mm; locality TU 953, Moín, Costa Rica (X ½).

REVIEWS

THE DARK SIDE OF THE EARTH, by Robert Muir Wood. Published by George Allen & Unwin, London, 1985, x + 246 pp., illus., hard cover, $19.95

The author reviews geological thought (in the broad context of the Earth as a whole) from the emergence of geology (about 1800) to the present. He paints with a bold brush, imputing to changing concepts over eighteen decades a series of Kuhnian paradigms rooted in the conflicts and competition between geologists and physicists for theoretical supremacy and leading to a revolutionary "science of the whole Earth", an unified Theory of the Earth known as Plate Tectonics.

Though the text is well written and polished, he fails to prove his thesis, "almost a century of silence" leading to "an eruption of activity" at the "culmination of the 1960s." The later history of conceptual geology is not catastrophic as many writers such as Wood would have us believe. The "Revolution" of 1965 is the culmination of decades of devoted research by thousands of geologists and geophysicists contributing to an orderly progression (dare I call it uniformitarian? – but NOT steady state) leading inevitably to Plate Tectonics. The pages of this scholarly volume confirm the unbroken progression; there was no hiatus.

GEOLOGY OF NATIONAL PARKS, third edition, by Ann G. Harris and Esther Tuttle. Published by Kendall/Hunt Publishing Company, Dubuque, Iowa, 1984, viii + 554 pp., illus., paper bound, $27.95

This, like previous versions, is a veritable text book of physical and historical geology, illustrated by the National Parks. The volume is arranged in six parts based on fundamental dynamic geology, e. g., stream erosion and weathering, glaciers and glacial processes, igneous activity and vulcanism, mountain building and uplift, ground-water action, and the spectacular "last" frontier of geology, the seven new national parks in Alaska.

At this time, there are forty-eight National Parks; twelve are new since the previous editon of this work. Each is described and discussed in clear language designed to be intelligible to readers not schooled in the earth sciences as well as for trained geologists. Some, especially the more famed and accessible ones, are presented in detail; others less well-known and not as thoroughly studied are less fully described. This volume is well done and most useful.

MIGRATION OF SEISMIC DATA, edited by Gerald H. F. Gardner; Geophysics Reprint Series, No. 4 (series editor Franklyn K. Levin). Published by Society of Exploration Geophysicists, Tulsa, Oklahoma, 1985, viii + 462 pp., illus., paperbound, $19.00

The thirty-three papers selected for this reprint volume sample the literature on migration between 1937 and 1984, arranged in chronological order to demonstrate the evolution of migration studies from the simple ruler-and-compass constructions used in earlier years to the present-day computer algorithms for depth migration in three dimensions.

The interpretative value of migration was recognized early in the 1920's, when single fold reflection profiles were used to pick two-way traveltimes for echoes from the interfaces between formations. Circular arcs were drawn with their centers at shot-receiver midpoints on the ground and radii equivalent to half the product of the traveltimes and the velocity of propagation in the subject lithology. Ideally, the circular arcs would define the interface, but time shifts in the measurements and velocity anomalies in the formation being traversed would cause variation in the radii. The interpreter of such data would them make a geologically reasonable "fit" from the construction. This simple construction is the basis for migration which is the summation of the wavefronts constructed from each sample value. The papers reprinted here trace the development of migration evaluation from simple graphical procedures to the modern computer-based techniques.

––H.C.S.

NOTES ON THE FAUNA OF THE CHIPOLA FORMATION - XXX
ON THE PRESENCE OF *EUDOLIUM (GALEODOLIUM) SUBFASCIATUM* SACCO (GASTROPODA: TONNIDAE)

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In the exposures of the Chipola Formation along Tenmile Creek, Calhoun County, Florida, we have taken a number of specimens of a genus hitherto unreported in the fossil record of the Western Hemisphere, although it is widespread in the Tertiary beds of the Old World. In the Recent waters of the western Atlantic there are but two species referred to this genus, both occurring in moderately deep water. Thus, the identification of specimens of *Eudolium subfasciatum* Sacco, 1890, in the Chipola Formation is of more than routine interest.

Sacco named *Eudolium subfasciatum*, along with twelve varieties, from the "Elveziano" (mid-Miocene) beds of northern Italy and Austria, but it is obvious that all of his specimens are referable to one variable species. Turner, in her study of the family Tonnidae (1948, p. 166), observed: "All species [in this family] appear to be exceedingly variable, not only to size, but also in coloration, sculpture and general shape of the shell." Certainly, this is the case in *E. subfasciatum* in the Chipola Formation, where we have some two dozen examples from seven localities. The number and strength of the spiral cords is different, not only among different specimens, but also in different growth stages of the same specimen. The strength of the nodes on the major cords and the number of noded cords also varies, there being from one to four such ornamented spiral cords, although the usual number is three.

In the Recent fauna of the western Atlantic there are only two species of *Eudolium*, both referable to *Eudolium* s.s. (*E. crosseanum*, the type of the genus, and *E. thompsoni* McGinty, 1955). Both are inhabitants of moderately deep water and neither is particularly similar to the fossil species. Sacco erected a subgenus *Galeodolium* for *E. subfasciatum* and the writer feels that there is a valid need for this taxon. Dr. Alan Beu, of the New Zealand Geological Survey and leading student of the Tonnacea, is of the opinion (*in litt.* 20 Dec. 1985) that *Galeodolium* (as well as Sacco's other supraspecific taxa proposed at the same time) and *Eudolium* are synonyms, with the differences between the forms being of specific rank only. However, it would appear that there are two distinct lineages within the *Eudolium* line. True *Eudolium* is first seen in the Oligocene with *E. antiquum* Sacco (referred by him to "*Tuberculodolium*"), continues through the Mio-Pliocene with (probably) two species placed by Sacco in *Tuberculodolium*" and "*Simplicodolium*," respectively, and finally into the Recent with the two species here referred to *Eudolium* s.s. All of these forms have a very thin inner lip, little more than a callus wash; whereas, the two Oligo-Miocene species placed by Sacco in *Galeodolium* have a much heavier inner lip, with the posterior portion expanded into a flaring inductura, bearing numerous elongate rugae, and with another group of enlarged rugae at the posterior end, forming an anal notch.

In the western Pacific there are also species of *Eudolium* s.s., which are presumed to have descended from the Middle Miocene *E. biornatum* (Tate, 1893) from Muddy Creek, Victoria, Australia. However, in the Early Miocene of New Zealand there is another species referable to *Galeodolium*; indeed, *E. aoteanum* Beu (1970, p. 127, pl. 3, figs. 19-26) is so similar in appearance to *E. (Galeodolium) muticum* (Michelotti, 1861) from the Italian Oligocene that it must be a direct descendant. Both of these latter species differ from *E. subfasciatum* in having coarser axial nodules and in having the back of the outer lip less deeply excavated.

Occurring in the same area along Tenmile Creek is the superficially similar *Phalium (Semicassis) aldrichi* (Dall, 1890), which also has a noded shoulder and a pustulose inductura. However, the sharply recurved siphonal canal is an unmistakable identifier of the *Phalium*; furthermore, there is but one row of nodes always present on the shoulder of *P. aldrichi* and (usually) three cords on *E. subfasciatum*. The protoconch of *E. subfasciatum* is about four times the size of that of *P. aldridgei*.

As noted above, the species of *Eudolium* s.s. live in relatively deep water (*E. crosseanum* from 40 to 450 fms [73 to 822 m], *fide* Turner, 1948, pp. 179-180; *E. thompsoni* in 75 fms [137 m], *fide* McGinty, 1955, p. 80; the Pacific species *E. pyriforme* in 50-80 fms [91-146 m] and *E. inflatum* in 100 fms [183 m], *fide* Kira, 1962, p. 59) but there is no evidence that the beds along Tenmile Creek were deposited in water anywhere near that deep. According to Scolaro (1968, pp. 46-47), the water depth at Tenmile Creek during Chipola time was about 20 meters, an interpretation that is corroborated by the molluscan fauna in general. In view of the fact that the species occurs only along Tenmile Creek and has been taken nowhere else in the Chipola beds, possibly bottom sediment type had a greater control over the distribution of the animal than did water depth. The beds along Tenmile Creek are generally lower in carbonates and of finer grain size toward the western end (TU localities 70 and 655); localities toward the eastern end (TU 546, 830, and 998) are not different in any measurable parameter from those along the Chipola River (Furlong, 1980) and yet the species occurs at both ends of the Tenmile section in approximately equal numbers (see *Occurrence*, below) but not on the Chipola River. This problem has been encountered in other molluscan species (see Vokes, 1977, p. 146, for a discussion), and so far, no satisfactory answer has been achieved.

ACKNOWLEDGMENTS

The writer wishes to acknowledge the contribution of the late Mrs. Shirley E. Hoerle, who originally recognized our species as being the same as the European one. Alan Beu also made numerous suggestions as to the improvement of the manuascript, and the fact that the writer does not entirely agree with his generic concept of the group (while hastening to admit that he knows a whole lot more about the group than she does!), in no way diminishes her gratitude to him.

SYSTEMATIC PALEONTOLOGY

Superfamily TONNACEA Suter, 1913
Family TONNIDEA Suter, 1913
Genus EUDOLIUM Dall, 1889

Eudolium DALL, 1889, Harvard Mus. Comp. Zool., Bull., v. 18, p. 232 (new name for *Doliopsis* Monterosato, 1872, not Vogt. 1852, nor Conrad, 1865).

Type species: *Dolium crosseanum* Monterosato, 1869, by monotypy.

Subgenus GALEODOLIUM Sacco, 1891

Eudolium (Galeodolium) SACCO, 1891, Moll. Terr. Terz. Piemonte e Liguria, pt. 8, p. 4.

Type species: *Cassidaria mutica* Michelotti, 1861, by subsequent designation, Cossmann, 1903.

Discussion: Sacco named *Galeodolium* as a "Sezione" of the genus *Eudolium*, including two nominal species: *E. muticum* (Michelotti), with three varieties; and *E. subfasciatum*, n. sp., with twelve varieties. He did not designate a type species but Cossmann (1903, p. 139), in a confusing account of the family Doliidae (*i.e.*, he places Sacco's *Galeodolium*, *Tuberculodolium*, and *Simplicodolium* in synonymy with *Dolium*, but includes the species Sacco assigned to these groups in the subgenus *Eudolium*), noted that in the Oligocene there are two species of *Eudolium*: "type de *Galeodolium* et de *Tuberculodolium: E. antiquum* Sacco, *Cassid. mutica* Michelotti." This is considered a valid designation of the type species for both taxa, even though the order of the two names is reversed.

EUDOLIUM (GALEODOLIUM) SUBFASCIATUM Sacco
Text figs. 1-3

Eudolium subfasciatum SACCO, 1890, Soc. Geol. Ital., Bol., v. 9, p. 201 (including 12 varieties and subvarieties; all nude names, list only); 1890, Mus. Zool. e Anat. Comp. Torino, Bol., v. 5, no. 86, p. 22 (including described varieties: *supratuberculifera*, *unituberculfera*, *percostata*; and nine undescribed varieties).

Eudolium (Galeodolium) subfasciatum Sacco. SACCO, 1891, Moll. Terr. Terz. Piemonte e Liguria, pt. 8, p. 6, pl. 1, fig. 4 (+ varieties *subtuberculata*, p. 7, pl. 1, fig. 5; *magnovoidea*, p. 7; *conica*, p. 7; *supratuberculifera*, p. 8, pl. 1, fig. 6; *oblongata*, p. 8, *pantanensis*, p. 8; *unituberculifera*, p. 8, pl. 1, fig. 7; *percostata*, p. 8, pl. 1, fig. 8; "subvariety" *crassilabiata*, p. 9; *tuberculifera*, p. 9; and *inflata*, p. 9, all from the Turin Hills; and *trilatetuberculata*, p. 7, from Grund, Vienna Basin, Austria).

Dolium (Eudolium) subfasciatum (Sacco). COSSMANN, 1903, Essais Paléoconch. Comp., v. 5, p. 138, pl. 5, fig. 18.

Discussion: This species occurs in the "Helvetian" of northern Italy and the Vienna Basin, and is here reported from the Burdigalian of northwestern Florida. Other than the Oligocene *E. muticum* and the New Zealand Miocene *E. aoteanum* there are no other members of *Galeodolium* presently known anywhere. All of the other species (including those referred by Sacco to *Tuberculodolium*, which lack the reflexed and denticulated outer lip, and *Simplicodolium*, which lack both the outer lip and the nodulose spiral cords) are placed in *Eudolium* s.s., the type of which has a reflected outer lip but no strong inner lip. The true extent of generic variation is uncertain due to the fact that entire specimens are rare in the fossil record; because of the extremely thin shells most are broken. In the Chipola material we have many more broken shells, or fragments, than entire specimens.

The wide distribution of *E. subfasciatum* is not unexpected in view of the fact that the type species of *Eudolium*, *E. crosseanum*, occurs from the Mediterranean, the south Atlantic and Indian Ocean to as far north as Natal, South Africa (Barnard, 1963, p. 8) and the western Atlantic, with records in the latter from New Jersey to Barbados (Turner, 1948, p. 180).

Occurrence in the Chipola Formation (number of specimens in parentheses): all localities on Tenmile Creek, between Florida Highway 70 and the base of the formation - from west to east - TU locality numbers 70(2), 655(4), 456(2), 546(5), 998(2), 951(4), 830(8).

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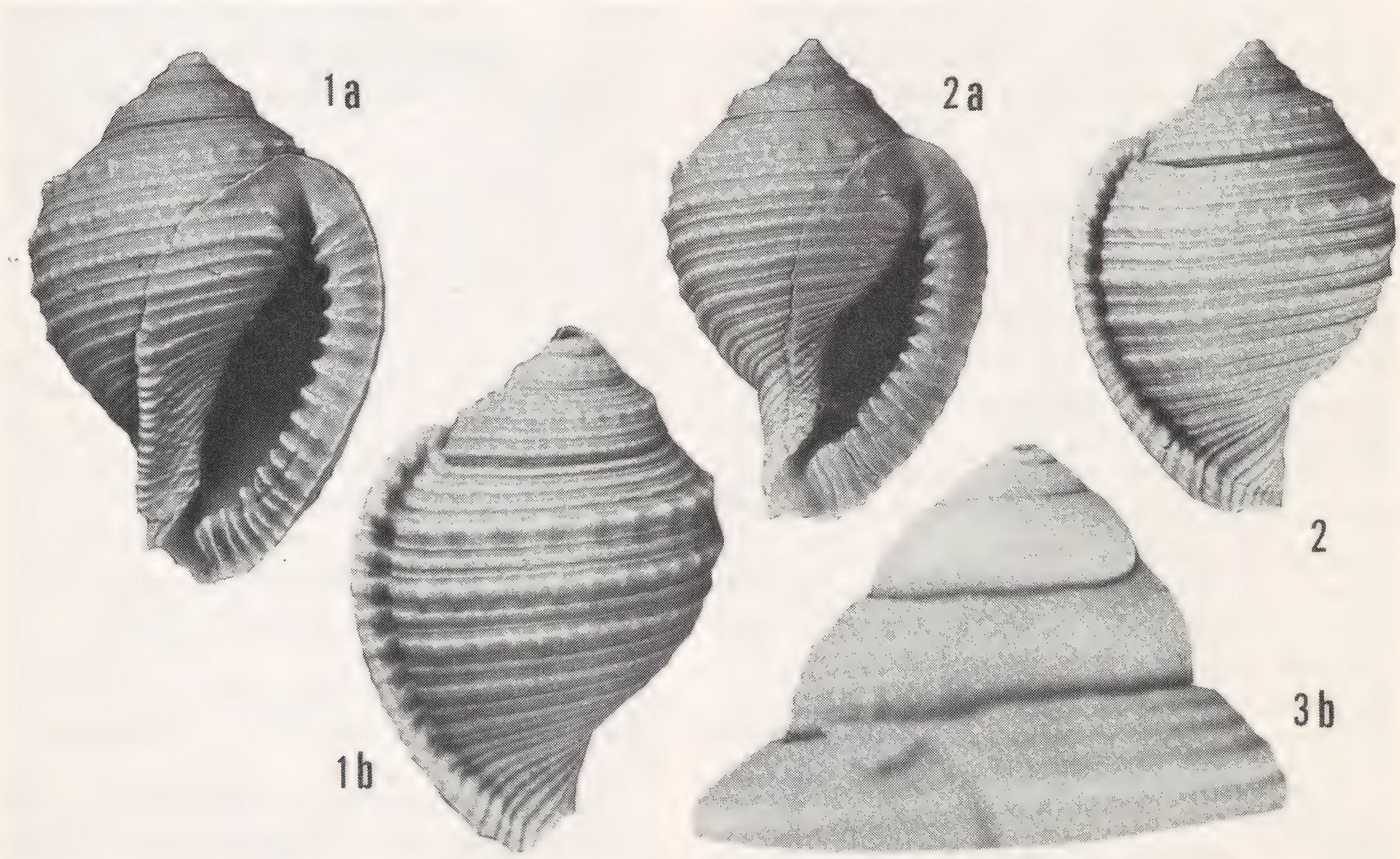

Text figure 1 (X 1 1/4), USNM 404594; height 36.8 mm, diameter 26.1 mm; locality TU 998. Text figure 2 (X 1), USNM 404595; height 44.4 mm, diameter 31.4 mm; locality TU 655. Text figure 3 (X 10), USNM 404596; height 14.7 mm, diameter 8.9 mm; locality TU 546. All localities on Tenmile Creek, Calhoun County, Florida.

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December 15, 1986

REVIEW

PALAEOFLORA OF SOUTHERN AFRICA: Prodromus of South African Megafloras, Devonian to Lower Cretaceous, by John M. Anderson and Heidi M. Anderson. Published by A. A. Balkema, Rotterdam, The Netherlands, for the Botanical Research Institute, 1985, 423 pp., 8 1/2 x 12 inches, illus., atlas of 226 pls., index, $55.00

This study is concerned with the floras and evolutionary trends preserved in the fossil record of South Africa from the Devonian to the Lower Cretaceous (from the appearance of vascular land plants to the rise of the flowering plants) which coincides broadly with the Pangaeic phase of Earth history. Specimens of land plants have been collected actively since 1845 by at least 35 individuals; succinct biographies of these collectors are included in the volume, as a record of the history of collecting. It is mainly a pictorial catalogue, but is divided into seven distinct sections, as follows: 1) Global & African Setting, in which a global and continental fabric, against which to visualise the successive South African megafloras is developed (with maps of the drifting continents, phylogenetic charts depicting the evolution of vascular plants and the evolution of vertebrate faunas, and a sequence of locality maps for each geological period, Devonian to Cretaceous); 2) Localities, Assemblages, Associations, Environment (with floristic tables, locality maps, and photos of localities for the eighteen successive megafloras recognized and documented); 3) Pre-Angiosperm Megafloral Succession (with the principal features of megafloral evolution outlined for South Africa, compared and contrasted with patterns for Gondwana and Pangaea); 4) Collectors (with biographical sketches intended to give a succinct account of the history of megaplant fossil collecting in South Africa); 5) Taxonomic Revision (with systematic revision undertaken for 91 genera and 263 species of South African megafloral taxa); 6) Photographic Catalogue (with 226 plates, 1888 individual photos, 111 genera, and 259 species); and, 7) Bibliography (nearly 500 references, classified and detailed). A glossary and an index are appended.

This comprehensive compilation is impressive and should be most useful for the specialized student of the megafloras of South Africa. It appears so comprehensive that there should be little need for future attention to this subject.

--H.C.S.

EARLY PLIOCENE *MONTFORTELLA* (FORAMINIFERIDA) FROM ECUADOR

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This article is dedicated to
R. W. Crouch
(1921 - 1984)

ABSTRACT

The genus *Montfortella* Loeblich and Tappan, 1963, is documented from Quebrada Camarones, Ecuador, in sediments of Early Pliocene age. This record represents the oldest known occurrence of this genus to date and also the first known occurrence in Ecuador. Observations are made on morphologic modifications of the intercameral openings, and the suggestion is made that these modifications permit improved seawater circulation from one surface of the test to the other, plus possibly enhance osmotic interaction between the foraminiferan and the seawater.

The oldest previously documented stratigraphic occurrence of the genus *Montfortella* Loeblich and Tappan, 1963, is from Early Pliocene (planktic zone N19) sediments exposed on the Isthmus of Tehuantepec, Mexico (Kohl, 1985). The genus ranges from the Early Pliocene to the Modern (Loeblich and Tappan, 1963; McCulloch, 1977; Kohl and Haman, 1980). The purpose of this article is to document for the first time the presence of this genus in the Pliocene of Ecuador. This record also represents the oldest stratigraphic occurrence for the genus.

In October 1980, the senior author was sent specimens of *Montfortella* by the late R. W. Crouch. The locality data provided was "Esmeraldas fm. Quebrada Camarones, Ecuador. On cliff above A. A. Olsson loc." Olsson (1942, p. 260) states "The name Esmeraldas formation may be given to the highly foraminiferal tuffaceous shales so extensively exposed along the coast of Esmeraldas and along the Esmeraldas river itself." This casual reference by Olsson (1942) has been criticized by Bristow (1976, p. 193) who stated, "The Esmeraldas Formation...was never properly defined by Olsson. From his descriptions it is evident that it includes most outcrops of the Onzole Formation, but locally (Quebrada Camarones) the Angostura Formation, and probably in the Esmeraldas area, some or all of the Borbón Formation." Cushman and Stainforth (1951) regarded the Rio Camarones (=Quebrada Camarones) beds as late Middle to early Upper Miocene and referred to them as part of the Borbón Formation. Hoffstetter (1956), in his review of the coastal stratigraphy of Ecuador, also did not accept the Esmeraldas Formation as described by Olsson.

As can be seen, the rock stratigraphic nomenclature at Quebrada Camarones is confused. The stratigraphy of this area is under detailed evaluation by E. H. Vokes (in press). She recognizes the Esmeraldas Formation and defines the type locality as "Quebrada Camarones, cut-bank on east side of canyon, which is at east edge of village of Camarones, 20 km. (by road) east of bridge over Rio Esmeraldas, at Esmeraldas, *or* approximately 5 km. east of mouth of Rio Esmeraldas, Prov. of Esmeraldas, Ecuador." This locality has been designated as Tulane locality TU 1397. The Crouch sample was collected by Mr. W. D. Pitt and termed sample B. Mr. Pitt (pers. comm. Jan. 1985) stated "When Olsson collected the cliff, he collected float material from the base of the cliff as it is too steep to collect the different strata on the face. In looking at the cliff, locality B was at the left hand side and was from a large block that had fallen from near the top of the cliff."

It is clear from microfaunal analysis that the Crouch-Pitt sample and the TU 1397 sample are coeval. The TU 1397 sample has been dated (Kohl *in* Vokes, in press) as planktic zone N18/19 and we have dated

the Crouch-Pitt sample as the same age. Locality maps provided for this exposure by Mr. Pitt and Professor Vokes demonstrate that their respective localities are in fact the same.

Two specimens of *Montfortella* were obtained from the Quebrada Camarones sample. One (Pl. 1, Figs. 1-4) has well defined sutural openings while in the other (Pl. 1, Figs. 5-6) the sutural openings are infilled and resisted cleaning efforts. The possible life mode of *Montfortella* and the role of the sutural openings have been discussed in Kohl and Haman (1980). The Ecuadorian specimens do permit us to make further observations on the sutural openings. It has been noted (Loeblich and Tappan, 1963; McCulloch, 1977; and Kohl and Haman, 1980) that the intercameral sutural openings are slit-like in character. The opening displayed by one of our specimens along the suture between the penultimate and broken presumably ultimate chamber indicates a flute-like modification to the basic slit (see Pl. 1, Fig. 4). This modification is located at the penultimate chamber margin side of the opening. Similar fluting can also be seen on the ultimate chamber margin side of the opening (Pl. 1, Fig. 2). The functional morphology of this fluting is open to question. McCulloch (1977) has suggested that these slits allow seawater to circulate to the attached side of the test. If this suggestion is accepted, it may be further postulated that the fluting of the slits increases the surface area within the slits which could, in turn enhance any osmotic exchange between the seawater and the foraminiferan.

We retain our Ecuadorian specimens in the species *Montfortella bramlettei* Loeblich and Tappan, 1963.

As stated, two specimens of *Montfortella* were obtained in this study. This may be regarded as a very rare occurrence especially as other sessile forms such as *Cibicides* are fairly common. The associated benthic foraminiferal assemblage is rich and diverse, composed of *Allomorphina, Amphistegina, Bolivina, Brizalina, Bulimina, Cassidulina, Discorbis, Elphidium, Gaudryina, Gyroidina, Hanzawaia, Lagena, Lenticulina, Martinottiella, Nodosaria, Pullenia, Quinqueloculina, Reussella, Saracenaria, Trifarina, Uvigerina, Vaginulina,* etc. This association suggests a mixture of two distinct foraminiferal assemblages which represent two different paleoenvironments. This interpretation agrees well with the concept of Vokes (in press), based on molluscan assemblages, that the Esmeraldas Formation represents a deep water environment with interspersed shallow water gravity flow lenses. We regard the deep-water microfaunal elements as representing an outer shelf/upper slope paleobathymetry while the shallow water benthic components represent an inner to middle shelf environment.

The planktic component is diverse with in excess of ten species of planktic foraminifera and in excess of four diagnostic species of calcareous nannoplankton. The planktic components allow us to date the subject sample as zone N18/19 (earliest Pliocene); which verfies the Kohl *in* Vokes (in press) determination.

ACKNOWLEDGMENTS

The authors are indebted to H. Crouch, W. D. Pitt, and E. Vokes for unpublished information supplied for this article; K. L. Finger, R. E. Marolt and P. E. Koeppel, for technical support, E. E. Schwartz for secretarial support, Chevron Oil Field Research Company and Chevron U.S.A., Inc. for publication permission, and to the late R. W. Crouch who was aware of our interest in the subject genus and who kindly drew our attention to the Ecuador specimens.

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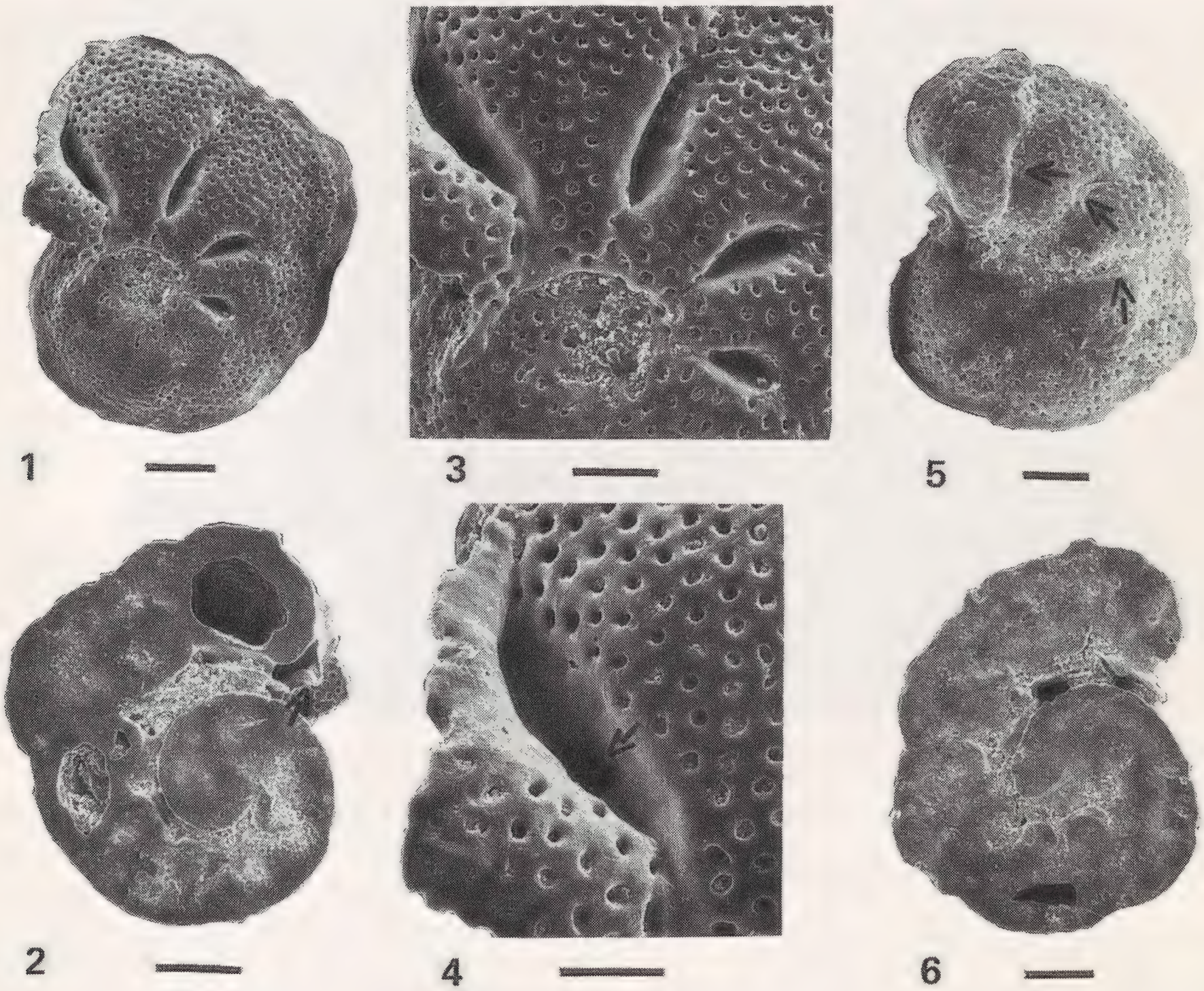

PLATE 1

Montfortella bramlettei Loeblich & Tappan

Bar = 50 μm (figs. 1, 2, 5, 6), = 25 μm (figs. 3, 4).

Figures

1, 2. Umbilical and spiral views. Arrow on fig. 2 indicates fluting of intercameral opening.

3. Detail of intercameral sutural openings.

4. Detail of opening along intercameral suture between penultimate and ultimate chamber. Arrow indicates area of fluting.

5, 6. Umbilical and spiral views. Arrows on fig. 5 indicate infilled intercameral openings.

VIGNETTES OF COASTAL PLAIN GEOLOGY

JOSEPH AUGUSTINE CUSHMAN
(1881-1949)

Joseph Augustine Cushman joined the United States Geological Survey, in 1912, to work on Foraminifera in the Coastal Plain Section; the first employment of a specialist on Foraminifera to work as a stratigraphic paleontologist and marking the beginning of a new era in Gulf Coast geology. His conviction that the smaller foraminifers were valuable for stratigraphic correlation led to the present day field of Stratigraphic Micropaleontology. (*From* L. G. Henbest, 1952, Geological Society of America, Proceedings)

KARRERIELLA OBTURACULOIDES, A NEW AGGLUTINATED BENTHIC FORAMINIFERAL SPECIES

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INTRODUCTION

In Quaternary samples from the Rio Grande Rise in the southwest Atlantic Ocean, a benthic agglutinated foraminiferal species occurs that has also been observed in other medium to deep-water Atlantic (Cushman, 1922), Gulf of Mexico (Flint, 1897), Indian Ocean (Boltovskoy, 1978) and Pacific (Taylor, in preparation) localities. It has been variously referred to *Gaudryina filiformis* Berthelin, *G. pseudofiliformis* Cushman and *G. bradyi* Cushman. However, a careful examination of type illustrations indicates no affinity of the present specimens to these, or any other described species. Thus, a new species is required to accommodate these specimens.

MATERIALS

Materials used for this study were from the following localities:

(1) Quaternary; DSDP Site 357 (Leg 39) on the Rio Grande Rise, southwest Atlantic Ocean; latitude 30° 00.25′S, longitude 35° 33.59′W. Core levels: core 1, Section 1, 82-92 cm; core 1, Section 2, 80-86 cm.
(2) Recent; HMS *Challenger*, Station 24, off Culebra Island, north of St. Thomas Island, West Indies; depth, 720 meters.

METHODS

Thirty specimens from two localities were examined variously in reflected light, transmitted light, and with a scanning electron microscope to study the test surface, apertural form and position, and the test interior in whole and half longitudinal, and cross sections. For sectioning, specimens were embedded in Lakeside 70 and carefully ground on 15-micron wet/dry emery paper until the inner structure of the test was exposed. The specimens were then immersed in alcohol overnight to dissolve the Lakeside 70, mounted on a plug, coated with gold, and illustrated with a scanning electron microscope. Two specimens were etched at the base to show early chamber arrangement using the method described by Plummer (1951).

Scanning electron micrographs of some of the sectioned, etched, and other selected specimens were taken with an ISI Super-111A Scanning Electron Microscope using Polaroid NP 55 film.

TYPE SPECIMENS

The figured holotype, figured paratypes, and unfigured paratypes are deposited in the United States National Museum, Washington, D. C.

ACKNOWLEDGMENTS

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SYSTEMATIC DESCRIPTION

Suborder TEXTULARIINA
Delage and Hérouard, 1896
Superfamily ATAXOPHRAGMIACEA
Schwager, 1877
Family EGGERELLIDAE Cushman, 1937
Subfamily EGGERELLINAE Cushman, 1937
Genus *Karreriella* Cushman, 1933
KARRERIELLA OBTURACULOIDES, n. sp.
Plate 1, Figures 1-8

Gaudryina filiformis Berthelin. FLINT, 1899, p. 287, pl. 33, fig. 2 (non *G. filiformis* BERTHELIN, 1880, p. 25, pl. 1, fig. 8).

Gaudryina pseudofiliformis Cushman. CUSHMAN, 1922, p. 78, pl. 13, fig. 5 (non *Gaudryina pseudofiliformis* CUSHMAN, 1911, p. 70, fig. 3).

Karreriella bradyi (Cushman). BOLTOVSKOY, 1978, p. 162, pl. 4, figs. 28, 29 (non *Gaudryina bradyi* CUSHMAN, 1911, p. 67, fig. 107).

Diagnosis: A species of *Karreriella* with an elongate, minimally tapering test, and sutures perpendicular to the longitudinal axis.

Description: Test free, elongate, megalospheric specimens initially triserial and circular in section, later becoming biserial and slightly compressed; microspheric specimens with five globular chambers in the initial whorl, then becoming triserial, and rounded in section, finally biserial and compressed in the later stage; sutures slightly to moderately incised, perpendicular to the longitudinal axis; wall thick and finely agglutinated, distinctly canaliculate, with fine internal pores terminating beneath the test surface; aperture a straight slit, parallel to and slightly above the inner margin of the final chamber, may be bordered by a slightly raised lip.

Derivation of Name: From the Latin, *obteraculum*, n., stopper, plug, = *-oides* like, resembling, having the form of, with reference to the shape of the test.

Dimensions: Maximum length, 1500 microns; maximum width 400 microns.

Types and Occurrence: Oligocene to Recent. Holotype (USNM 383403), figured paratypes (USNM 383404), and unfigured paratypes (USNM 383405), all from DSDP Site 357 (Leg 39); Rio Grande Rise in the southwest Atlantic Ocean; latitude 30°00.25′S, longitude 30°33.51′W; Core 1, Section 1, 82-92 cm Quaternary. Figured paratype (USNM 383406) and unfigured paratype (USNM 383407), both from HMS *Challenger* Station 24, off Culebra Island, North of St. Thomas Island, West Indies; depth, 720 meters. The species also has been reported from Recent samples in the Gulf of Mexico, off the west coast of Cuba at 720 meters, in the Indian Ocean at 2237 meters and on the Lord Howe Rise in the Pacific Ocean at 1399 meters.

Remarks: In recent literature this species frequently has been referred to *Gaudryina bradyi* Cushman, which it superficially resembles. However, *G. brady* differs from the present species in tapering strongly toward the base and in the oblique sutures (approximately 25° to the longitudinal axis). *Karreriella obturaculoides* also has been referred to *Gaudryina pseudofiliformis* Cushman, but in addition to the radically different aperture, the latter species is also considerably more elongate and compressed than the present species. *Gaudryina filiformis* Berthelin is much smaller and more elongate than *K. obturaculoides*. Most of the specimens observed in this material were megalospheric specimens. As asexual megalospheric forms normally dominate foraminiferal

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PLATE 1

Karreriella obturaculoides, n. sp.

1,2. Side view of megalospheric holotype (USNM 383403). 1, view showing sutures perpendicular to longitudinal axis, X 130. 2, same enlarged to show slightly areal aperture parallel to inner margin of final chamber, X 225. DSDP Site 357, Core 1, Section 1, 82-92 cm.

3. Basal view of etched megalospheric paratype (USNM 383404) showing rounded section and triserial arrangement of some initial chambers, X 100. DSDP Site 357, Core 1, Section 1, 82-92 cm.

4,5. Oblique view of megalospheric paratype (USNM 383404). 4, specimen showing rounded base, becoming slightly compressed in later chambers, X 100. 5, enlargement of areal aperture, showing partly developed apertural lips, X 485. DSDP Site 357, Core 1, Section 1, 82-92 cm.

6. Half section of megalospheric paratype (USNM 383404), showing thickened walls of specimen and chamber arrangement near proloculus, X 65. DSDP Site 357, Core 1, Section 1, 82-92 cm.

7. Edge view of megalospheric paratype (USNM 383404) showing slightly compressed test and depressed sutures, X 50. DSDP Site 357, Core 1, Section 1, 82-92 cm.

8. Side view of microspheric paratype (USNM 383406) showing the characteristic small proloculus, X 115, HMS *Challanger* Station 24, off Culebra Island, West Indies, depth 720 meters.

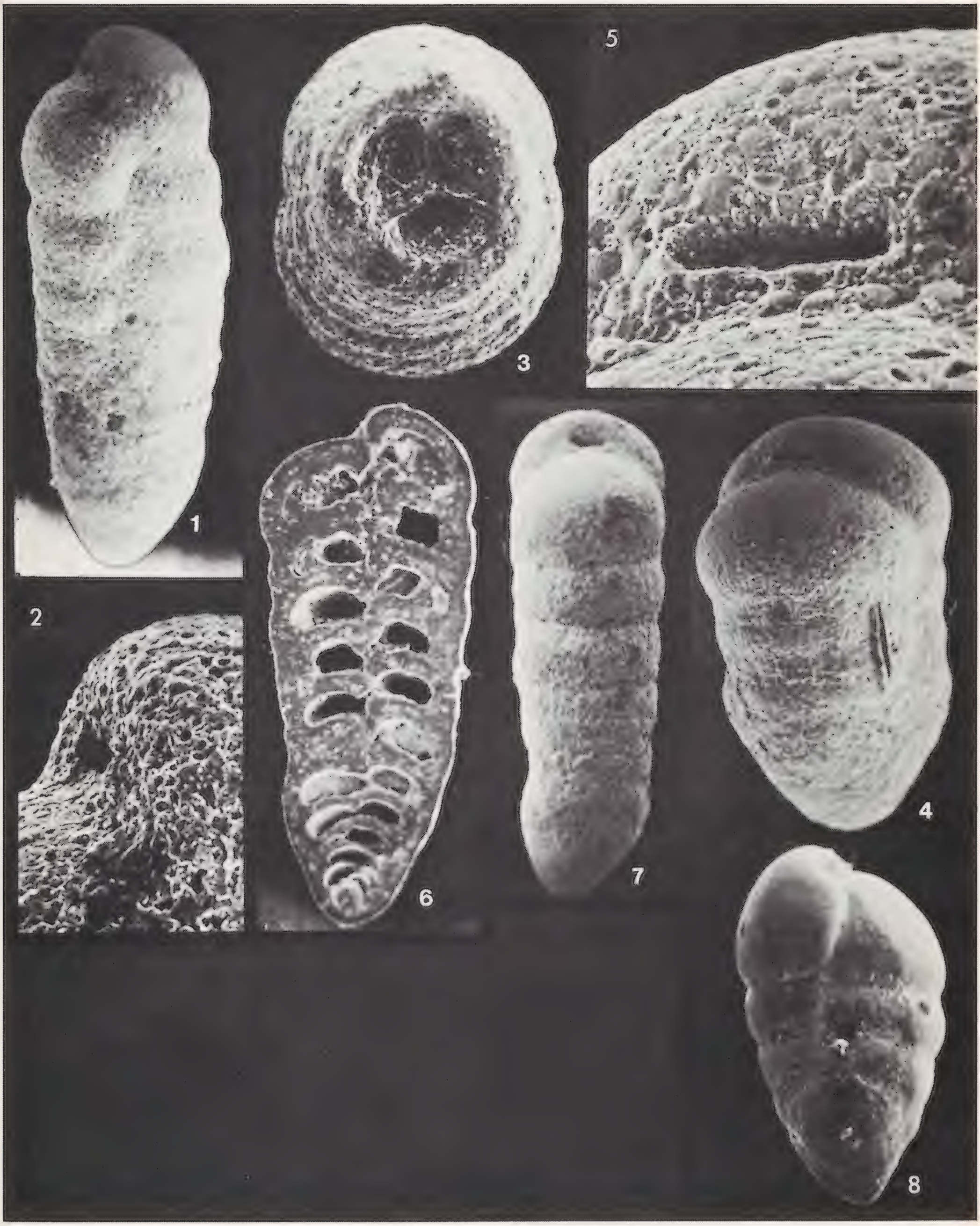

PLATE 1

populations the scarcity of microspheric forms in these relatively small samples is not remarkable.

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AMPLECTODUCTINA, A NEW FORAMINIFERAL GENUS IN THE SIPHOGENERINOIDIDAE

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ABSTRACT

Amplectoductina, a new genus of the Tubulogenerininae, is distinguished by its entirely uniserial chamber arrangement. The type of the new genus is *Amplectoductina carnatolintra.*

Various genera of the foraminiferal family Siphogenerinoididae have been defined on the basis of such morphological characters as the number of initial chambers, apertural configuration, and the orientation of the toothplate in successive chambers (Saidova, 1981; Loeblich and Tappan, 1982).

Among benthic foraminifera in Pleistocene to late Oligocene samples from DSDP Site 357 (Leg 39) on the Rio Grande Rise is a species of Siphogenerinoididae which, except for being entirely uniserial, fits all criteria used to define Tubulogenerininae. Although rare in individual samples, it is found at several core levels. As all specimens are uniserial, the species is most likely uniserial in both generations, rather than representing the megalospheric generation of an initially triserial or biserial species. This totally uniserial early chamber arrangement, in conjunction with other characteristics, excludes the species from previously described genera. Therefore, a new genus is required for placement of the species.

The subfamily Tubulogenerininae, as previously defined (Saidova, 1981), included all those genera with tests triserial or biserial in the early stage, later becoming uniserial, whose triserial ancestry is reflected internally by successive hemicylindrical toothplates each oriented 120° from the preceding. The aperture is terminal and circular, with a short neck or thickened rim. Specimens of the new genus display a hemicylindrical toothplate oriented at 120° from the preceding, indicating triserial ancestry. Rather than erect a new subfamily for this probably closely related genus, the subfamily Tubulogenerininae Saidova (1981) is herein emended to include entirely uniserial species as well.

Twenty-six specimens from fifteen core levels at a single locality were studied under a binocular microscope. Both transmitted and reflected light were used to determine the morphologic variation, and the nature of an internal toothplate. The outer wall was partially removed from three specimens using the method described by Plummer (1951). Scanning electron micrographs were taken with an ISI-111A Scanning Electron Microscope, and Polaroid NP 55 film.

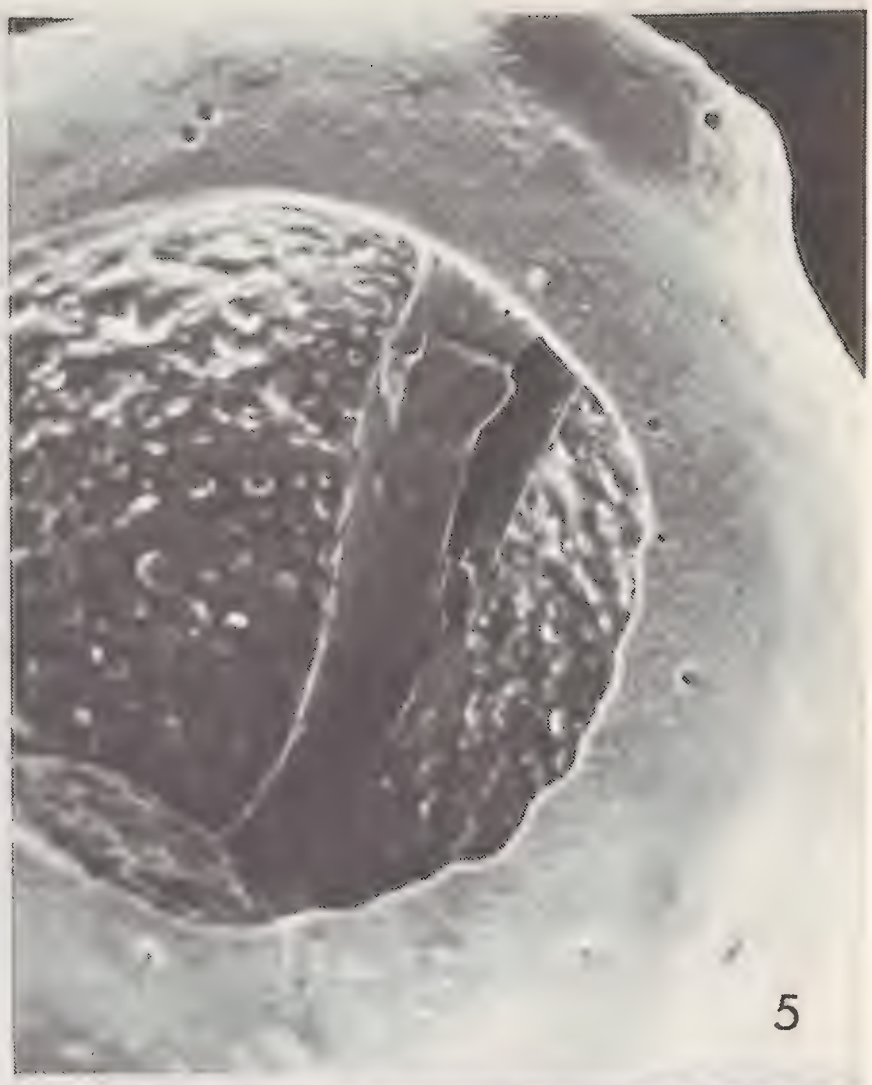

PLATE 1

1-5. *Amplectoductina carnatolintra,* n. sp., from DSDP Site 357 (Leg 39). Fig. 1, side view of holotype (USNM 383524) showing longitudinal costae and size increase in successive chambers, 357-5-3, 80-86 cm, Pliocene, X 100; Fig. 2, side view of stouter, less elongate paratype (USNM 383526), 357-2-4, 83-89 cm, Pliocene, X 80; Fig. 3, apertural view of paratype (USNM 383525) showing 21 costae and small circular aperture surrounded by rim, 357-4-5, 80-86 cm, Pliocene, X 195; Fig. 4, section of paratype (USNM 383527) showing successive hemicylindrical toothplates, X 100; Fig. 5, enlargement of final chamber of same paratype showing tubular toothplate at base becoming broader and hemicylindrical at top of chamber, X 370; Fig. 6, enlargement of base of same toothplate showing attachment of tubular base to previous apertural opening, X 530, Core 1, Section 4, 80-86 cm, Pleistocene.

Materials used for this study came from fifteen core levels of DSDP Site 357 (Leg 39) on the Rio Grande Rise, southwest Atlantic Ocean; 30°00.25′S, 35°33.59′W. The core levels were:

1. Pleistocene; 357-1-4, 80-86 cm.
2. Pliocene; 357-2-1, 80-86 cm.
3. Pliocene; 357-2-4,83-89 cm.
4. Miocene; 357-4-5, 80-86 cm.
5. Miocene; 357-5-1, 80-90 cm.
6. Miocene; 357-5-3, 80-86 cm.
7. Miocene; 357-5-5, 80-86 cm.
8. Miocene; 357-8-5, 85-91 cm.
9. Miocene; 357-10-3, 82-88 cm.
10. Miocene; 357-12-1, 82-88 cm.
11. Miocene; 357-13-1, 82-88 cm.
12. Miocene; 357-14-1, 80-86 cm.
13. Miocene; 357-14, corecatcher.
14. Oligocene; 357-17-1, 80-86 cm.
15. Oligocene; 357-17-5,80-86 cm.

The holotypes, figured paratypes, and unfigured paratypes are deposited in the U.S. National Museum of Natural History, Washington, D.C.

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SYSTEMATIC DESCRIPTIONS

Suborder ROTALIINA Delage and Hérouard, 1896

Superfamily BULIMINACEA Jones, 1875

Family SIPHOGENERINOIDIDAE Saidova, 1981

Subfamily TUBULOGENERININAE Saidova, 1981

AMPLECTODUCTINA, n. gen.

Type species: Amplectoductina carnatolintra, n. sp.

Diagnosis: A genus of Tubulogenerininae with numerous longitudinal costae and an entirely uniserial test.

Description: Test free, uniserial, elongate, circular in section; sutures straight and partially incised; wall calcareous, hyaline, surface with numerous longitudinal costae, nonporous; aperture circular and lipped; hemicylindrical toothplates oriented 120° to each other in succeeding chambers, toothplates initially tubular, opening to form a hemicylinder part way up to next chamber.

Etymology: From the Latin, *amplector*, wind, twine, embrace + *ductus*, a leading, tube, pipe + *-ina*, diminutive, with reference to the orientation of the internal toothplate. Gender feminine.

Remarks: Amplectoductina, n. gen., differs from *Orthokarstenia* Dietrich, 1935, in lacking triserial and biserial early stages, lobulate reentrants on the lower margin of each chamber, and the semicylindrical spout arising from the apertural lip. *Clavelloides* De Klasz and Rerat, 1962, is similar to *Amplectoductina* in possessing uniserially arranged, longitudinally costate chambers, but it lacks the raised apertural lip and more significantly has adjacent chambers connected by a closed tubular process rather than an alternating hemicylindrical toothplate. *Siphogenerinoides* Cushman, 1927, has a biserial early stage, clearly differentiating it from the entirely uniserial *Amplectoductina*, although the arrangement of the toothplate is similar in the two genera.

AMPLECTODUCTINA CARNATOLINTRA, n. sp.

Pl. 1, Figs. 1-6

Diagnosis: A species of *Amplectoductina* with 20-22 longitudinal costae and rapidly enlarging chambers.

Description: Test free, uniserial, elongate, increasing rapidly in size with addition of each new chamber, circular in section, broadest at penultimate chamber; wall calcareous, hyaline, smooth between costae, pores associated with costae but do not penetrate outer wall; no pores are found in test wall proper; approximately 20-22 longitudinal costae, those extending length of test alternating with costae extending only two-thirds length of test or less, upper half of last

chamber free of costae; aperture small and circular surrounded by raised lip; each successive hemispherical toothplate oriented 120° from that preceding, toothplates narrow and tubular at base of each chamber and becoming much broader and hemicylindrical toward top of each chamber.

Etymology: From the Latin, *carnatus*, fleshy, corpulent, fat, + *linter*, *tris*, tub, vat, with reference to the stout test.

Dimensions: Maximum length, 720 microns; maximum width, 330 microns.

Types and occurrence: Pleistocene, Pliocene, Miocene, and Oligocene from DSDP Site 357 (Leg 39), Rio Grande Rise in the Southwest Atlantic Ocean, 30°00.25′S, 35°33.59′W. Holotype (USNM 383524) from 357-5-3, 80-86 cm, Miocene. Figured paratype (USNM 383525) from 357-4-5, 80-86 cm. Miocene; figured paratype (USNM 383526) from 357-2-4, 83-89 cm, Pliocene; and figured paratype (USNM 383527) from 357-1-4, 80-86 cm, Pleistocene. unfigured paratypes (USNM 383528) from 357-5-1, 80-90 cm, Pliocene.

Remarks: This species is externally similar to several species of *Orthomorphina* Stainforth, 1952. These include: *Nodosaria marginulinoides* Silvestri, 1872; *Nodosaria erbessina* Schwager, 1878; *Nodosaria bambergensis*, Franke, 1936; *Nautilus (Orthoceras) comatus* Batsch, 1791; *Othocerina multicostata* Bornemann, 1854; and *Pseudoglandulina multicostata* (Bornemann) var. *semicostata* Barnard, 1950. All are generally similar to the present species in shape and have comparable numbers of costae, but they all lack internal toothplates and are thus unrelated to *Amplectoductina carnatolintra*. *Ellipsoglandulina multicostata* (Galloway and Morrey), as figured by Douglas (1973, p. 630, pl. 5, fig. 8), may be the present species. However, examination of the type illustration of *Daucina multicostata* Galloway and Morrey, 1929, shows that this species has a crescentic aperture. As Douglas makes no reference to either the nature of the aperture or to any internal structure, affinity of his specimen with the present species is uncertain.

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